JUL 2 1980

Item 431-A-20

TD 4.32/EE80 1/v.2

COMPLETED

ORIGINAL

Report No.FAA-EE-80-1, Vol II

CORRECTION PROCEDURES FOR AIRCRAFT NOISE DATA
VOLUME II
BACKGROUND NOISE CONSIDERATIONS

WYLE RESEARCH
El Segundo, California

L. Sutherland
J. Parkinson
D. Hoy

December 1979

FINAL REPORT

Document is available to the U.S. public through
The National Technical Information Service
Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Environment and Energy
Washington, D.C. 20591

115

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

9

Technical Report Documentation Page

1. Report No.
FAA-EE-80-1, Vol. II

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Correction Procedures for Aircraft Noise Data
Volume II: Background Noise Considerations

5. Report Date
December 1979

6. Performing Organization Code

7. Author(s)
L. Sutherland, J. Parkinson, D. Hoy

8. Performing Organization Report No.
WR 79-9

9. Performing Organization Name and Address
Wyle Research
El Segundo, California 90245

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-FA78WA-4143

12. Sponsoring Agency Name and Address
Federal Aviation Administration
Office of Environment and Energy
800 Independence Avenue, SW.
Washington, D.C. 20591

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
AEE-110

15. Supplementary Notes

16. Abstract

The impact of background noise on the value of PNL, PNLT, and the resulting EPNL noise metric in aircraft certification to FAR Part 36 is examined in this report, the second in a series of reports on aircraft noise measurement correction procedures. Procedures to remove background noise effects from data measured in the form of one-third octave band sound pressure levels for jet and large propeller aircraft, or data in the form of A-weighted noise levels for light propeller driven aircraft, are defined. After evaluating various techniques for different ratios of signal-to-background noise, one simple correction method for turbojet/turbofan aircraft noise is proposed. The recommended method consists of applying an energy correction, up to a maximum of -10 dB, for that portion of the background noise spectra dominated by energy-adding or predetection background noise. For the remaining portion of the background noise spectra, the non-additive postdetection background noise floor tends to mask out bands very close to or below this noise floor. A simple spectrum extrapolation procedure is recommended in this case. Another background noise correction method for light propeller aircraft noise is also proposed. This procedure simply involves application of an energy correction to the "as measured" A-weighted aircraft signal using the A-weighted background noise level. Procedures are also suggested for measuring the background noise level in order to account for the randomness of the fluctuating background noise level.

17. Key Words
Aircraft Noise; Noise Certification; Correction Procedures; Background Noise

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
114

22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

b

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

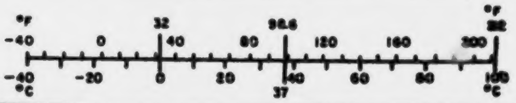
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

---

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ABSTRACT

The impact of background noise on the value of PNL, PNLT, and the resulting EPNL noise metric in aircraft certification to FAR Part 36 is examined in this report, the second in a series of reports on aircraft noise measurement correction procedures. Recommended procedures to remove background noise effects from data measured in the form of one-third octave band sound pressure levels for jet and large propeller aircraft, or data in the form of A-weighted noise levels for light propeller driven aircraft, are defined. To evaluate background noise corrections for jet aircraft noise measurements, representative spectra of several commercial turbojet/turbofan aircraft with different noise frequency characteristics are examined using already developed and two new background noise correction methods. After evaluating the various techniques for different ratios of signal-to-background noise, one simple correction method is proposed for consideration as an "FAA approved" method. The recommended method consists of applying an energy correction, up to a maximum of -10 dB, for that portion of the background noise spectra dominated by energy-adding or predetection background noise. For the remaining portion of the background noise spectra, the non-additive postdetection background noise floor tends to mask out bands very close to or below this noise floor. A simple spectrum extrapolation procedure is recommended in this case. Another background noise correction method for light propeller aircraft noise is also proposed for consideration as an "FAA approved" method. This procedure simply involves application of an energy correction to the "as measured" A-weighted aircraft signal using the A-weighted background noise level. Procedures are also suggested for measuring the background noise level in order to account for the randomness of the fluctuating background noise level.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

2.0 GENERAL NATURE OF BACKGROUND NOISE . . . 3

  2.1 Temporal and Spectral Characteristics of Background Noise 7

    2.1.1 Temporal Characteristics 9

    2.1.2 Spectral Characteristics 11

  2.2 Measurement of Background Noise Levels . . . 16

    2.2.1 Measurement of Predetection Background Noise . 16

    2.2.2 Measurement of Postdetection Background Noise 17

    2.2.3 Simple Test to Distinguish Types of Background Noise 18

3.0 BACKGROUND NOISE CORRECTION METHODS - JET AND LARGE PROPELLER DRIVEN AIRCRAFT 19

  3.1 General Approach Currently Defined by the Regulation . 19

  3.2 Specific Approaches to Background Noise Corrections . 20

    3.2.1 Application of Band Deletion Provisions of Current Regulation 22

    3.2.2 FAA Correction Procedures 26

    3.2.3 DOT/TSC Correction Method . . . 27

    3.2.4 NASA/Dytec/Douglas Correction Methods . 27

    3.2.5 Proposed SAE Method 28

    3.2.6 Boeing Method 28

    3.2.7 BBN Method 29

  3.3 Relative Merits of Alternate Correction Methods . . 30

    3.3.1 Do-Nothing Approach 31

    3.3.2 Delete "Violating" Bands Without Replacement . 31

    3.3.3 Extrapolate in Frequency with Fixed Slope . 31

TABLE OF CONTENTS (Continued)

3.3.4 Extrapolate, in Frequency with a Slope Based On The Available "Nonviolating" Bands . . . 39

3.3.5 Fixed Extrapolation Model in the Time Domain . 39

3.3.6 Extrapolate in Time with a Slope Based on the Available "Nonviolating" Bands . . . 42

3.3.7 Energy Subtraction Methods 46

3.3.8 Combined Methods 48

3.4 Specific Correction Methods Developed for this Report . 48

3.5 Quantitative Comparison of Correction Methods . . 51

3.5.1 Aircraft Signal and Background Noise Spectra Used for Evaluation 51

3.5.2 Results 52

3.5.3 Maximum Allowable Background Noise Level . 62

4.0 BACKGROUND NOISE CORRECTION METHODS - LIGHT PROPELLER AIRCRAFT 63

4.1 Analytical Basis for Correction Method . . . 63

4.2 Field Measurement Procedure 67

5.0 RECOMMENDATIONS FOR BACKGROUND NOISE CORRECTIONS TO NOISE CERTIFICATION MEASUREMENTS FOR AIRCRAFT . 69

5.1 Correction Procedure for Jet and Large Propeller Aircraft 69

5.2 Correction Procedure for Light Propeller Aircraft . . 71

APPENDIX A - AIRCRAFT NOISE DATA ACQUISITION AND PROCESSING A-1

APPENDIX B - STATISTICAL CONSIDERATIONS IN BACKGROUND NOISE CORRECTIONS B-1

APPENDIX C - TIME HISTORIES OF SELECTED ONE-THIRD OCTAVE BAND LEVELS FROM ONE 727 TAKEOFF C-1

APPENDIX D - TIME HISTORY OF MOVING MONOPOLE SOURCE IN MEDIUM WITH ATMOSPHERIC ABSORPTION LOSSES D-1

LIST OF TABLES

Table		Page
1	Review of General Features of Published Background Noise Correction Procedures	21
2	Range of Predicted High Frequency Attenuation Rates, in dB/Octave from 5 to 10 kHz, for PNLTM Spectra for Various Aircraft, Operating Conditions and Weather	38
3	Original and New "As Measured" 727 Takeoff Spectra and Corresponding Background Noise Levels to Create 4 and 7 Violations of 5 dB S/N Ratio	53
4	Original and New "As Measured" 727 Approach Spectra and Corresponding Background Noise Levels to Create 4 and 7 Violations of 5 dB S/N Ratio	54
5	Comparison of Results of Applying Various Correction Procedures for Background Noise to Two Representative Aircraft Spectra	59

LIST OF FIGURES

Figure		Page
1	Conceptual Illustration of Elements of Background Noise Encountered in the Acoustic Measurement of Aircraft Noise	4
2	Illustration of Time History of Linearly Increasing Signal in the Presence of Varying Levels of Predetection (Acoustical or Electrical) Background Noise Relative to the Postdetection Background Noise Floor of the Signal Analyzer	8
3	Time History of 2 One-Third Octave Bands from a Typical Aircraft Flyby Illustrating How (a) Ambient (Additive) Noise Dominates the Background Noise at 400 Hz, and (b) Postdetection (Non-additive) Noise Dominates the Background Noise at 6300 Hz	10
4	Partial Printout of Spectral Time History During an Aircraft Flyover	12
5	Range of Median One-Third Octave Band Levels of Typical Daytime Ambient Noise in Urban and Suburban Communities; Based on Extensive Octave Band Spectra Measured in Three Different Studies	13
6	Typical Components of Background Noise in Output of Aircraft Noise Measurement System	15
7	Representative Spectra Used to Demonstrate Effect of Deleting Bands Nearest to Background Noise Spectrum for Computation of PNL	24
8	Effect on PNL or PNLT of Deleting Bands for Aircraft Spectra in Figure 7	25
9	PNLTM Spectra Normalized to 300 m, 25°C, 70% RH - 10 m Microphone over Hard Ground	32
10	Estimated Variation in PNLTM Spectra for 727 (from Figure 9) Due to Changes in Propagation Distance (R) and Weather	34
11	Comparison of Measured Time History of Relative One-Third Octave Band Level at 3150 Hz from 727 on Approach with Values Predicted by Three Different Versions of a Simple Moving Monopole Source Model	41
12	Comparison of Measured Time History of Relative One-Third Octave Band Level at 80 Hz from 727 on Takeoff with Values Predicted by Simple "Static" Model for Moving Monopole Source (Directivity, Kinematic and Acoustic Effects of Motion Ignored)	43

LIST OF FIGURES (Continued)

Figure		Page
13	Rate of Change of Level Observed Near Simple Moving Monopole Source in a Uniform, Still, Lossy Atmosphere	45
14	Criteria for Signal-to-Noise Ratio for Background Noise Correction Procedures	47
15	727 Takeoff with Background Noise Raised to Create Four Bands in Violation of 5 dB Requirement	55
16	727 Takeoff with Background Noise Raised to Create Seven Bands in Violation of 5 dB Requirement	56
17	727 Approach with Background Noise Raised to Create Four Bands in Violation of 5 dB Requirement	57
18	727 Approach with Background Noise Raised to Create Seven Bands in Violation of 5 dB Requirement	58

BACKGROUND NOISE CORRECTIONS

1.0 INTRODUCTION

Background noise is an ever present quantity which must be considered in the analysis of all physical measurements. This report is concerned with the impact of background noise on acoustic measurements made during aircraft certification to FAR Part 36. It is the second in a series of reports on various correction procedures for application to aircraft noise measurements.[15]*

The procedures and equipment required in the FAR Part 36 Regulation for noise certification of commercial turbojet and small business jet aircraft are described in Appendix A of the Regulation.[1] A greatly simplified equivalent of Appendix A, applicable to light propeller aircraft (<12,500 pounds) is provided in Appendix F of the Regulation. Each of these appendices include requirements that the effects of background noise be considered.

Processing of jet aircraft noise for certification involves a breakdown of the measured noise at one-half second time intervals into 24 one-third octave band sound pressure levels at preferred center frequencies covering the frequency range of 50 to 10,000 Hz. The effect of background noise on these levels is the principal subject of this report.

This effect is explicitly covered in the existing FAR Part 36 Appendix A requirement in Para. A36.5 (d)(3) that states, "Aircraft sound pressure levels within the 10 dB- down points must exceed the mean background sound pressure levels --- by at least 5 dB in each one-third octave band (or be corrected under an FAA approved method) to be included in the computation of overall noise level of the aircraft." Appendix A also states in Para. A36.3 (f)(3) that "when analyzed in PNL (Perceived Noise Level), the resulting measured background, noise level must be at least 20 PNdB below the maximum PNL of the aircraft." Correction for background noise for light propeller aircraft in Appendix F of the Regulation is limited to the requirement that the measured maximum A-weighted aircraft noise level must exceed the A-weighted background noise level by at least 10 dB, or corrections must be made to the measured data for the contribution of background noise by an approved method.

---

*Superscripts designate references listed at the end of this report.

This report examines correction for background noise in the context of Appendix A and Appendix F of FAR Part 36, and recommends correction methods which are considered as suitable candidates for FAA "approved methods" or which may be included in revisions to FAR Part 36.

In the next section, the basic nature of background noise is defined to lay groundwork for the remaining discussion. In Section 3 specific alternative correction procedures which have been reported in the literature and which are applicable to Appendix A of the Regulation are defined. The "correction" performance of these procedures is compared with that for two new methods developed for this study when all are applied to correct representative aircraft noise spectra contaminated, artificially, with varying degrees of background noise. The results of this comparison are presented in Section 3.3.

As outlined in Section 4, no specific procedures for correcting light propeller aircraft noise data (i.e., Appendix F) for background noise were found in the literature. However, a general approach is outlined for such a correction procedure based on a simple analytical model and an equally simple field method.

Finally, recommended procedures are summarized in Section 5 for consideration by FAA as candidate "FAA approved" methods for applying background noise corrections.

Supporting materials are contained in Appendices A through D.

- Appendix A describes the acquisition and processing of aircraft noise data utilized for this report.
- Appendix B outlines some statistical considerations in background noise corrections.
- Appendix C presents some detailed comparisons of aircraft flyover time histories measured with different microphone positions to assist in evaluation of temporal extrapolation techniques for background noise problems.
- Appendix D reviews the analytical basis for extrapolating an aircraft noise signal in the time domain based on the time history of noise from a moving nondirectional sound source.

2.0 GENERAL NATURE OF BACKGROUND NOISE

Before unambiguous correction methods for background noise can be developed, it is necessary to clearly establish just what is meant by the term "background noise" (it is often mistakenly called ambient noise). The correction methods to be recommended are, in fact, based on recognition of more than one form of background noise.

According to the pertinent American National Standard,[2] "background noise" is defined as:

> "the total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal."

"Ambient noise" on the other hand is defined as:

> "the all encompassing noise associated with a given environment, being usually a composite of sounds from many sources near and far. . . .Ambient noise detected, measured, or recorded with the signal becomes part of the background noise."

Therefore, throughout the remainder of the report, the term "background noise" will be understood to represent the overall total of all the sources of interference with the measurement of the true aircraft noise signal. This is also essentially consistent with usage of this term in the current FAR Part 36 Regulation,[1] hereinafter identified as simply the Regulation. The term "ambient noise" will be used, where necessary, to denote only the acoustical portion of the background noise.

Consider, now, a more specific definition of the various types of background noises.

Figure 1 provides a conceptual breakdown of an acoustic measurement system which illustrates the different types of background noise that can be present. These are:

N_A - Acoustic Background Noise or Ambient Noise which is detected by the microphone as an acoustic signal.

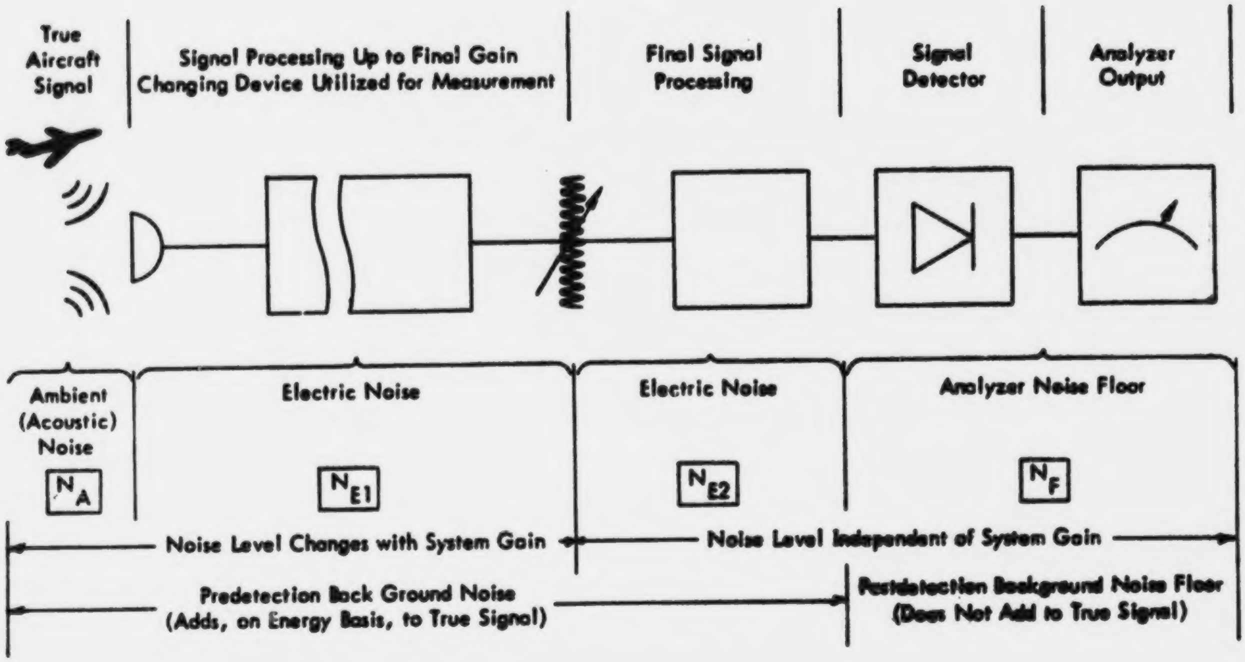

True Aircraft Signal
Signal Processing Up to Final Gain Changing Device Utilized for Measurement
Final Signal Processing
Signal Detector
Analyzer Output
Ambient (Acoustic) Noise
N_A
Electric Noise
N_{E1}
Electric Noise
N_{E2}
Analyzer Noise Floor
N_F
Noise Level Changes with System Gain
Noise Level Independent of System Gain
Predetection Back Ground Noise (Adds, on Energy Basis, to True Signal)
Postdetection Background Noise Floor (Does Not Add to True Signal)

Figure 1. Conceptual Illustration of Elements of Background Noise Encountered in the Acoustic Measurement of Aircraft Noise. The Four Elements Illustrated Can Be Categorized in Two Ways: The First Depends Upon the Way the Background Noise Level Changes with System Gain; the Second Depends Upon the Way the Background Noise Adds, or Does Not Add, to the True Aircraft Noise Signal.

N_{E1} - Variable Electric Background Noise consisting of wide band random noise or hum from AC power which is introduced electronically into the signal processing system prior to the final gain-changing attenuator utilized before detection of the total signal.

N_{E2} - Fixed Electric Background Noise of the same type as above, introduced between this last attenuator and the signal detection device. (The output of this detector is an analog or digital signal corresponding to the noise level applied to the input averaged over a period of at least one-half second.) With good system design, this portion of the electric background noise would be negligible but is included here for the sake of completeness.

N_F - Display Background Noise Floor, the minimum level which can be observed on the output display device. This noise floor is represented, for example, by the bottom scale marking on a sound level meter, the bottom of a graphic recorder chart, the bottom of an oscilloscope display of a spectrum analyzer, or the lowest level that can be printed out by a digital readout system.

As indicated in Figure 1, the output level of the first two elements of background noise change as the overall system gain changes, although not necessarily in a linear fashion, while the apparent output level of the last two elements of background noise remain constant. The potential nonlinear change in output level of the first two elements (i.e., the acoustic and variable portion of the electric background noise) can occur when system gain is controlled, as it usually is, at more than one position in the signal processing chain. In this case, only that portion of the background noise which is introduced into a system prior to any one gain-changing attenuator will change its output level linearly (decibel for decibel) corresponding to the change in attenuator gain. Electric background noise introduced into a system after this attenuator will, of course, not be influenced by its setting so that the total background noise level at the output may not change by exactly the same amount as the total change in system gain. Thus, it is necessary and sufficient, that, as specified by paragraph A36.3(f)(2) in the Regulation, when recording a sample of background noise, "each component of the (measurement) system must be set at the gain levels used for aircraft noise measurement." In other words, due to the potential nonlinear relationship between background noise level in the output and overall system gain, it is not enough to just duplicate this total system gain; the gain setting of each component of the data system must be the same for both background and aircraft noise measurements. This ensures that the background noise will be accurately measured.

Fortunately, for purposes of developing correction methods to account for background noise, the rather complex situation described so far can be greatly simplified by reducing background noise to just two types as illustrated in the lower part of Figure 1.

- Predetection Background Noise - consisting of the acoustic and electrical background noise, all of which adds, on an energy basis to, and is nominally indistinguishable from, the true aircraft acoustic signal; and
- Postdetection Background Noise - this is simply the noise floor of the display device. This "noise" does not add to the true signal.

While the existence of these two general types of background noise is undoubtedly well recognized in the industry, as discussed later, many of the published procedures for correcting aircraft noise data for background noise either do not explicitly distinguish between the two types or consider only one of the two types.

As shown by the next to the bottom row in Figure 1, background noise can be categorized in another way into just two types. This breakdown is based on whether or not the particular segment of the background noise changes (in this case, linearly) as the system gain is changed at the final attenuator utilized in the measurement system. As pointed out earlier, the fixed electric background noise component (N_{E2}) introduced into the system between this final attenuator and the signal detector is, for good engineering design, far below any of the other background noise components so that for all practical purposes, the noise component (N_{E2}) can be considered negligible and the two ways of categorizing background noise are, for all practical purposes, identical. That is:

- The level of predetection background noise, which adds on an energy basis to the signal, can be assumed to change, linearly, with the final system gain-changing attenuator, and
- The level of postdetection background noise, which does not add to the signal, is independent of the system gain.

These mutually exclusive characteristics of the two different types of background noise provide one indirect basis for being able to distinguish between predetection and postdetection background noise in the output.

To illustrate these two types of background noise types more clearly, examine the hypothetical output of a data analysis system with a time varying one-third octave band signal input and a postdetection background "noise floor" as shown in Figure 2. Let the signal to be measured, L(t), be increasing at the rate of, say, "m" dB/sec., i.e., $L(t) = mt$, dB. If the predetection background noise level is assumed, for now, to be a constant N dB and the postdetection background noise floor is N_F dB, i.e., no signal level can be observed in the output display device that is less than N_F, then the analyzer output level A(t) is given by:

$$A(t) = 10 \log \left[10^{L(t)/10} + 10^{N/10} \right] , \text{dB} \qquad (1)$$

except that A(t) will never be less than the noise floor N_F.

Values of A(t) that would be observed at one-half second intervals, are plotted in Figure 2 for $m = 3$ dB/sec, and $N = -20, -10, -5, 0$, and $+5$ dB relative to the postdetection background noise floor, N_F.

This idealized pattern for the time history of a linearly increasing signal in the presence of various levels of the two types of background noise clearly illustrates how the predetection noise begins to add significantly to the signal when the predetection background noise level is greater than about 10 to 15 dB below the postdetection background noise floor.

2.1 Temporal and Spectral Characteristics of Background Noise

When analyzing an aircraft flyover signal, the most obvious indication of the presence of background noise is often provided by distinct differences between temporal or spectral characteristics of the background and aircraft noise.

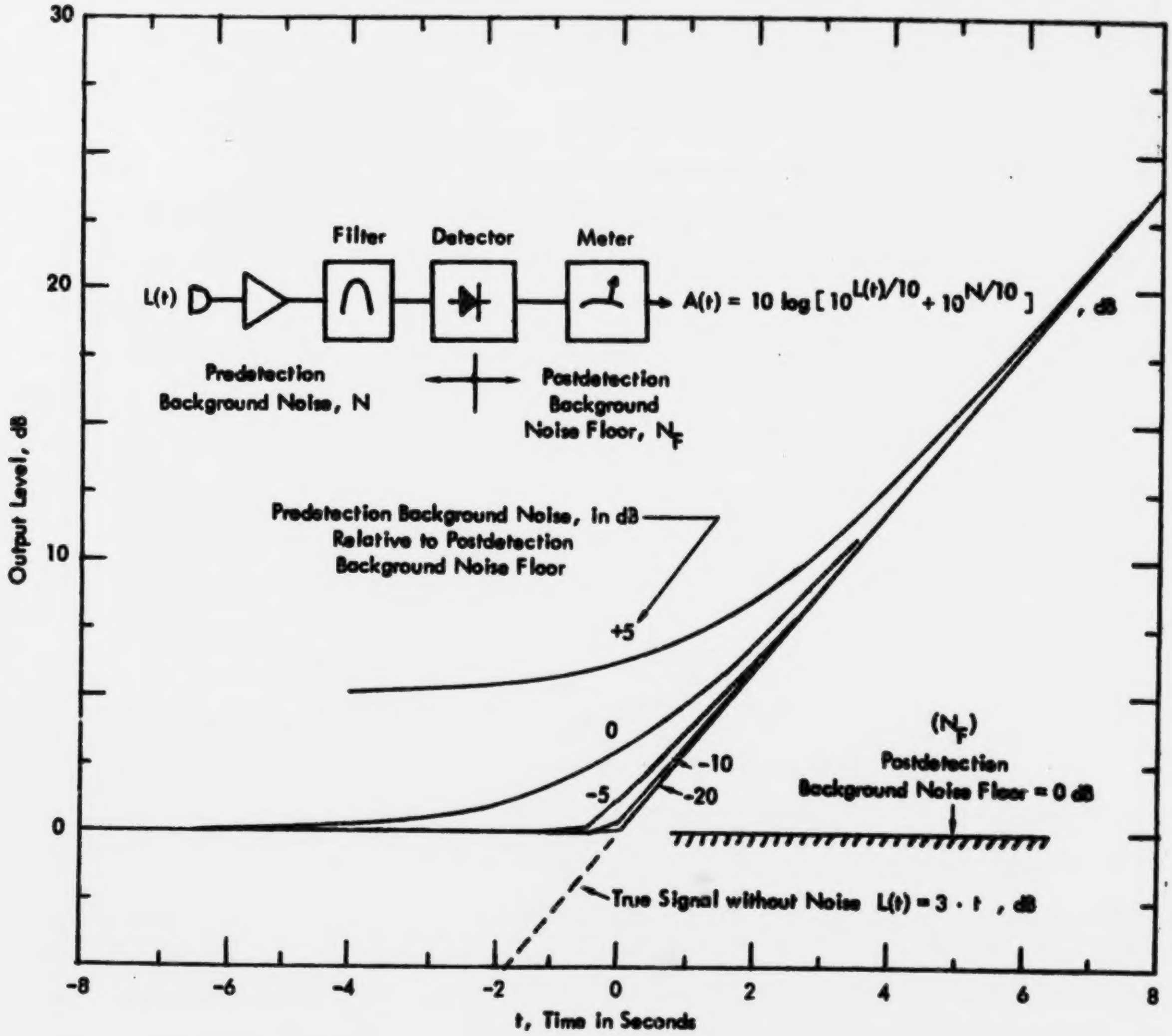


Figure 2. Illustration of Time History of Linearly Increasing Signal in the Presence of Varying Levels of Predetection (Acoustic or Electrical) Background Noise Relative to the Postdetection Background Noise Floor of the Signal Analyzer

2.1.1 Temporal Characteristics

Figure 3 presents typical time histories for two different one-third octave bands observed during an aircraft flyby which illustrate distinct differences in the time domain.

In each figure, vertical lines delineate the nominal time of occurrence (before correction for background noise) of the maximum tone-corrected perceived noise level (PNLTM) and the corresponding "10 dB-down" times. The data illustrated were obtained from an extensive set of aircraft noise measurements carried out, in support of this program, at Los Angeles International Airport. Details of these measurements are presented in Appendix A.

Figure 3a is for a one-third octave band at 400 Hz where the background noise is dominated by the acoustic component or ambient noise. This appears, in typical fashion, as a varying noise, fluctuating about some mean value. Clearly, therefore, any scheme which attempts to correct an aircraft noise signal for the influence of such an energy-additive fluctuating background noise is subject to an inherent statistical error since the level of the acoustic background noise, during the actual aircraft flyover, can only be estimated statistically on the basis of measurements of ambient noise before and after the aircraft flyover. A detailed consideration of this problem is not appropriate here and is relegated to Appendix B. This residual statistical error will be neglected for now and it will be assumed that the level of the background noise, during the time period of the aircraft flyover, has been accurately determined.

Figure 3b shows the time history, from the same aircraft flyover and noise measurement position as for Figure 3a, for the 6300 Hz band. In this case, the background noise is the postdetection background noise floor of the spectrum analyzer and digital system used to reduce the data. The aircraft signal rises above, and falls below, this nonadditive noise floor with essentially none of the characteristic rounding at the juncture, on the time axis, between a constant energy-additive background noise and a rising or falling signal such as illustrated earlier in Figure 2.

A slight rounding or gradual decrease in rate of change of the aircraft signal does appear in Figure 3b at the transition points at about 19.5 and 28

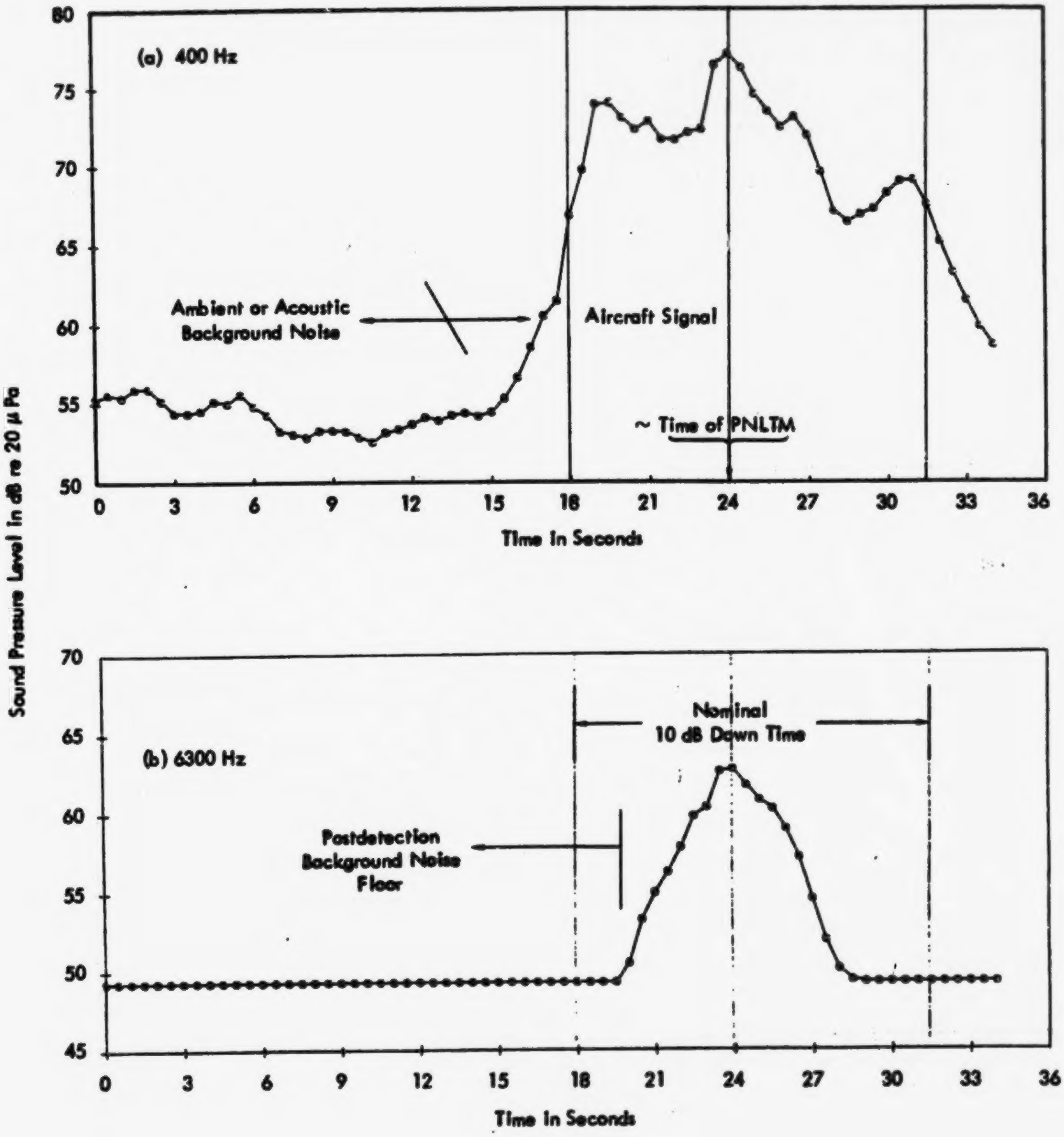


Figure 3. Time History of 2 One-Third Octave Bands from a Typical Aircraft Flyby Illustrating How (a) Ambient (Additive) Noise Dominates the Background Noise at 400 Hz, and (b) Postdetection (Non-additive) Noise Dominates the Background Noise at 6300 Hz

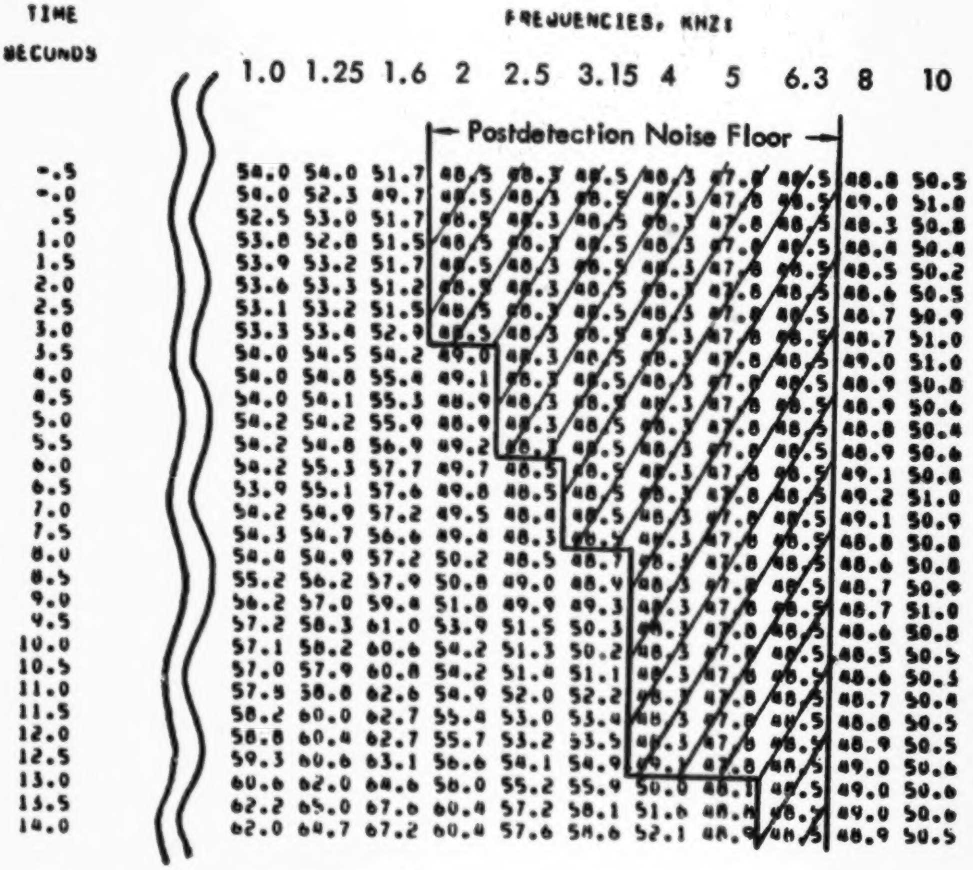
seconds. This is simply due to the temporal smoothing process utilized in the data processing over three successive one-half second data samples. This smoothing process is used to simulate the dynamic response characteristics required of the analyzer indicating device by Para. A36.3 (d)(5) of the Regulation (see Para. A.2 of Appendix A for further details).

One other feature of the temporal characteristics of background noise should also be pointed out since it provides one indirect way to distinguish, roughly, between predetection and postdetection background noise. This feature is the difference in temporal variation of these two components.

Predetection noise is normally a broadband random noise with significant random fluctuations over a period of 10 to 30 seconds which have typical standard deviations in one-third octave band levels of 1 to 3 dB over this period of time. Postdetection noise, on the other hand, is characteristically constant with time for any one sensitivity or gain setting of the output display device. Thus, as shown by the shaded area in Figure 4, a computer printout of one-third octave band levels at each one-half second from an aircraft flyover noise analysis will show a characteristic pattern of perfectly constant one-third octave band levels which serves to identify the presence of the postdetection background noise floor.

2.1.2 Spectral Characteristics

The typical spectrum of acoustic background or ambient noise in urban or suburban areas is well represented by the results, shown in Figure 5, from three independent studies of community noise.[3-5] The figure shows that the range of median one-third octave band levels (levels exceeded 50 percent of the time) from these three studies falls within a fairly narrow band over most of the audible frequency range. The spectrum shape exhibits a peak at a frequency of about 63 Hz and decreases at a rate of about 4.5 dB per octave above this frequency. Although the ambient noise spectrum shown in Figure 5 probably does not include any significant influence of noise from aircraft, such influence would not be expected to substantially change its spectrum shape. This was, in fact, borne out by the ambient noise levels observed during the aircraft noise measurements cited earlier. For these data, the ambient (acoustic) noise dominates the background noise at frequencies below 400 Hz and, in this low frequency region, the data show



```
TIME                                FREQUENCIES, KHZ:
SECONDS
              1.0  1.25 1.6  2    2.5  3.15 4    5    6.3  8    10
                             |- Postdetection Noise Floor -|
   -.5        54.0 54.0 51.7 48.5 48.3 48.5 48.3 47.8 48.5 48.8 50.5
   -.0        54.0 52.3 49.7 48.5 48.3 48.5 48.3 47.8 48.5 49.0 51.0
    .5        52.5 53.0 51.7 48.5 48.3 48.5 48.3 47.8 48.5 48.3 50.8
   1.0        53.8 52.8 51.5 48.5 48.3 48.5 48.3 47.8 48.5 48.4 50.4
   1.5        53.9 53.2 51.7 48.5 48.3 48.5 48.3 47.8 48.5 48.5 50.2
   2.0        53.6 53.3 51.2 48.5 48.3 48.5 48.3 47.8 48.5 48.6 50.5
   2.5        53.1 53.2 51.5 48.5 48.3 48.5 48.3 47.8 48.5 48.7 50.9
   3.0        53.3 53.4 52.9 48.5 48.3 48.5 48.3 47.8 48.5 48.7 51.0
   3.5        54.0 54.5 54.2 49.0 48.3 48.5 48.3 47.8 48.5 49.0 51.0
   4.0        54.0 54.8 55.4 49.1 48.3 48.5 48.3 47.8 48.5 48.9 50.8
   4.5        54.0 54.1 55.3 48.9 48.3 48.5 48.3 47.8 48.5 48.9 50.6
   5.0        54.2 54.2 55.9 48.9 48.3 48.5 48.3 47.8 48.5 48.8 50.4
   5.5        54.2 54.8 56.9 49.2 48.3 48.5 48.3 47.8 48.5 48.9 50.6
   6.0        54.2 55.3 57.7 49.7 48.5 48.5 48.3 47.8 48.5 49.1 50.8
   6.5        53.9 55.1 57.6 49.8 48.5 48.5 48.3 47.8 48.5 49.2 51.0
   7.0        54.2 54.9 57.2 49.5 48.4 48.5 48.3 47.8 48.5 49.1 50.9
   7.5        54.3 54.7 56.6 49.4 48.3 48.5 48.3 47.8 48.5 48.8 50.8
   8.0        54.4 54.9 57.2 50.2 48.5 48.7 48.3 47.8 48.5 48.6 50.8
   8.5        55.2 56.2 57.9 50.8 49.0 48.9 48.3 47.8 48.5 48.7 50.9
   9.0        56.2 57.0 59.4 51.8 49.9 49.3 48.3 47.8 48.5 48.7 51.0
   9.5        57.2 58.3 61.0 53.9 51.5 50.3 48.3 47.8 48.5 48.6 50.8
  10.0        57.1 58.2 60.6 54.2 51.3 50.2 48.3 47.8 48.5 48.5 50.5
  10.5        57.0 57.9 60.8 54.2 51.4 51.1 48.3 47.8 48.5 48.6 50.3
  11.0        57.5 58.8 62.6 54.9 52.0 52.2 48.3 47.8 48.5 48.7 50.4
  11.5        58.2 60.0 62.7 55.4 53.0 53.4 48.3 47.8 48.5 48.8 50.5
  12.0        58.8 60.4 62.7 55.7 53.2 53.5 48.3 47.8 48.5 48.9 50.5
  12.5        59.3 60.6 63.1 56.6 54.1 54.9 49.1 47.8 48.5 49.0 50.6
  13.0        60.6 62.0 64.6 56.0 55.2 55.9 50.0 48.1 48.5 49.0 50.6
  13.5        62.2 65.0 67.6 60.4 57.2 58.1 51.6 48.8 48.5 49.0 50.6
  14.0        62.0 64.7 67.2 60.4 57.6 58.6 52.1 48.9 48.5 48.9 50.5
```

Figure 4. Partial Printout of Spectral Time History During an Aircraft Flyover. Shaded Area Identifies Portion Dominated by Temporally-Constant Postdetection Background Noise. (Variation of These "Constant Levels" Between Frequencies Reflects Influence of Minor System Frequency Response Corrections Incorporated Into the Final Data.)

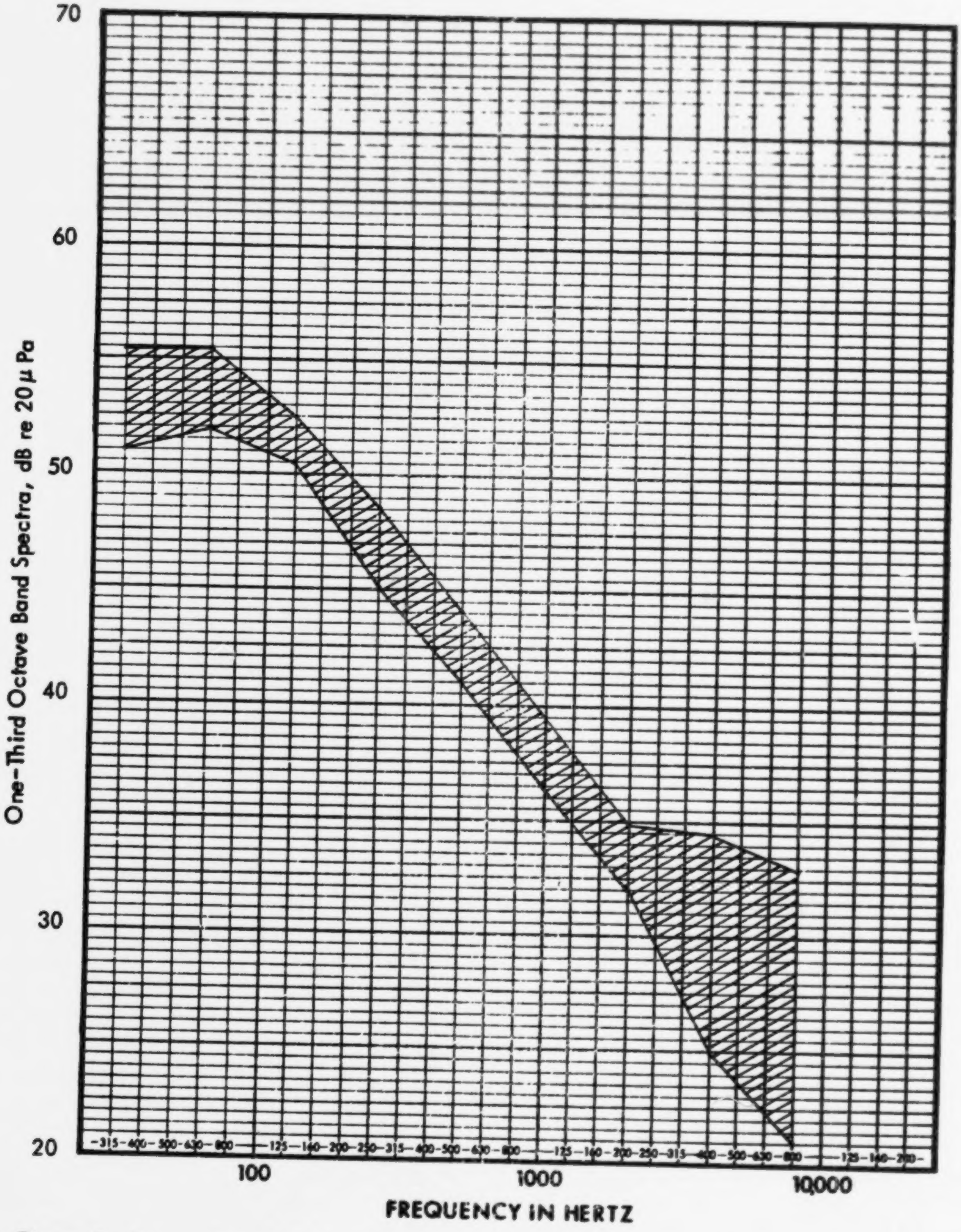


Figure 5. Range of Median One-Third Octave Band Levels of Typical Daytime Ambient Noise in Urban and Suburban Communities; Based on Extensive Octave Band Spectra Measured in Three Different Studies[3, 4, 5]

essentially the same spectrum shape as in Figure 5, but with levels increased by about 6 dB.

The spectrum shape of electric background noise in an acoustic measurement system can vary substantially, depending on the design characteristics of the system and the type and condition of any magnetic tape utilized for data recording. Advanced data systems may employ digital instead of analog magnetic recording techniques, in which case, the frequency sensitive electric noise of an analog recording system may be replaced by a uniform electric noise floor corresponding to the lowest analog signal level that is registered by the digital system (i.e., the signal level corresponding to one bit).

Figure 6 compares typical values for the electric background noise of a conventional (analog) aircraft noise measurement system with corresponding values for the acoustic background noise and representative values for the postdetection background noise floor. Note that all three of these elements of background noise can vary from flight to flight during the course of any series of aircraft noise measurements. The acoustic component varies at the output as a function of time and measurement component gain settings while the other two components vary as a function of the system gain settings only.

The electric and postdetection background noise levels shown in Figure 6 were selected to illustrate a very general case, although not necessarily a typical one. In this case, the electric background noise is sufficiently high to protrude above the postdetection background noise floor at the high frequency end of the spectrum. Thus, as shown in Figure 6, the total background noise splits into the two types - predetection and postdetection - cited earlier. However, the split is not necessarily defineable in terms of a single frequency below which only predetection background noise dominates and above which only postdetection background noise dominates. While this latter situation may be more frequently encountered in aircraft noise measurements (see Appendix A), the more general case illustrated in Figure 6 shows that the spectrum of the two types of background noise may appear as discontinuous segments. This same situation was also apparent in the partial listing of a spectral time history given earlier in Figure 4.

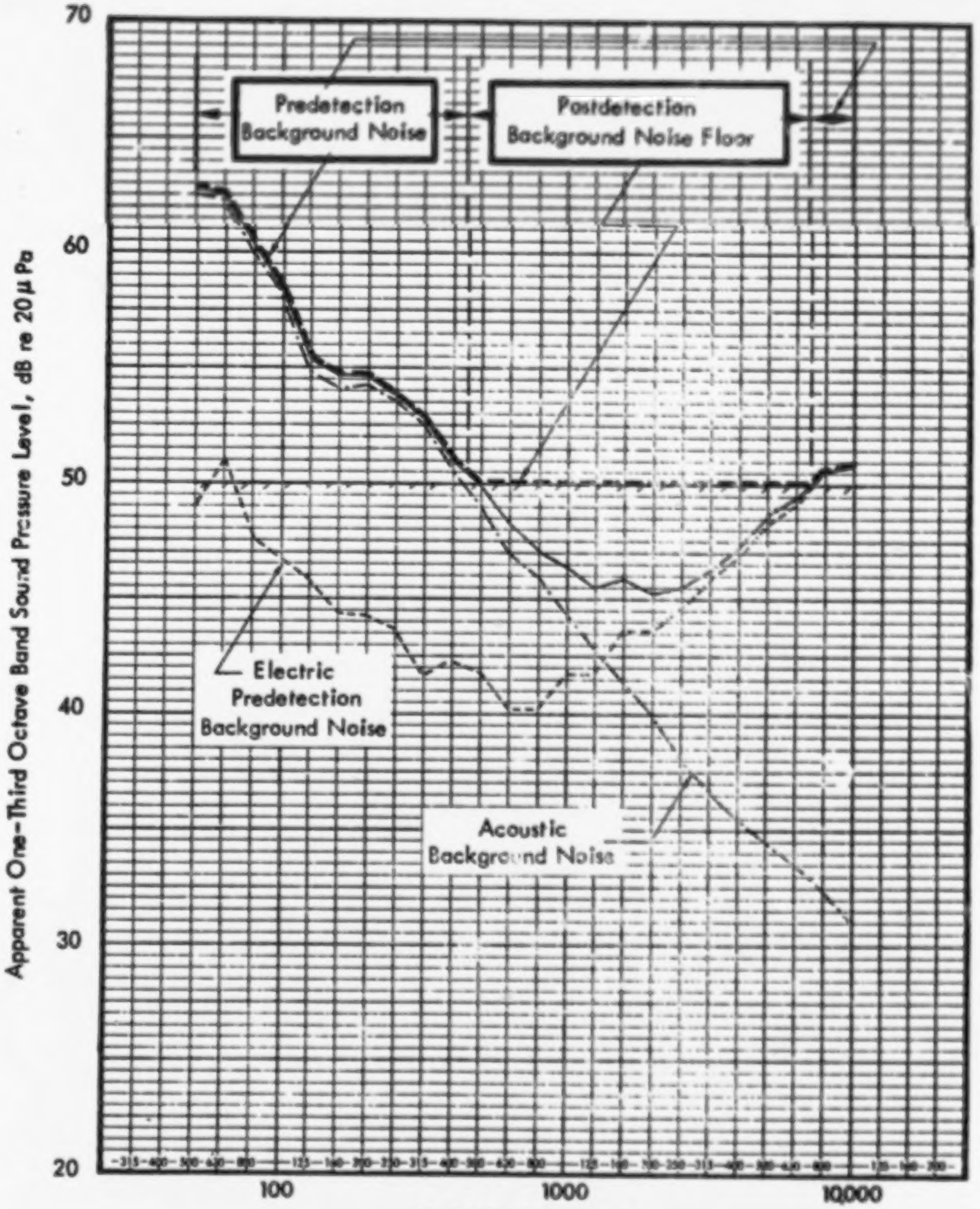


Figure 6. Typical Components of Background Noise in Output of Aircraft Noise Measurement System. This Illustrates a Case Where the Predetection Background Noise Appears at Both the Low and High Frequency End of the Spectrum.

2.2 Measurement of Background Noise Levels

The preceding paragraphs have illustrated some of the characteristic features which distinguish pre- and postdetection background noise. This attention to the temporal and spectral character of background noise has been provided in order to establish its general characteristics in sufficient detail to provide the foundation for a valid general correction method. Although some of these characteristics might be used in practice to make this distinction, during reduction of aircraft noise data, more direct methods of measurement can be readily employed.

The starting point for such direct measurements is the procedure specified in the Regulation for recording the ambient or acoustic background noise. For jet and large propeller aircraft, this procedure is specified in paragraph A36.3(f)(2)[1] as:

> "Immediately before and after each series of test runs, and after each day's testing, a recorded acoustic calibration of the system, prescribed in A36.3(e)(2) of this Appendix, must be made in the field to check the acoustic reference level for the analysis of the sound level data. Ambient noise must be recorded for at least 10 seconds and be representative of the acoustical background, including systemic noise, that exists during the flyover test run. During that recorded period, each component of the system must be set at the gain levels used for aircraft noise measurement."

Throughout this report, it will be assumed that, in response to this requirement, good engineering practice would dictate that a total of at least 20 seconds of ambient noise would be recorded for each test series - 10 seconds before and 10 seconds after.

The procedure for recording ambient noise for light propeller aircraft, cited in paragraph F36.107(c) of the Regulation, is essentially the same except that no specified duration is given for recording the ambient noise.

2.2.1 Measurement of Predetection Background Noise

Once the preceding background noise recording has been made with the proper gain settings, the actual levels of the predetection portion can be readily determined by analyzing this background noise data and adjusting the dynamic range of the output display device temporarily so that its postdetection noise floor is depressed below the lowest band level of the predetection background noise. For example, referring to Figure 6, if the sensitivity of the output display device were increased by 5 dB, the postdetection background noise floor would fall below the minimum one-third octave band level of the total predetection background noise (in this case 45.2 dB at 2000 Hz). The true level of this background noise component could then be read directly. As shown in Figure 6, this predetection background noise can consist of a combination of acoustic and electric noise. The latter will normally fluctuate in level in the usual manner as for any purely stationary random noise signal while the acoustic background noise, also usually random, can fluctuate even more due to the potential nonstationary character of the acoustic ambient noise. In any event, to be consistent with Paragraph A36.3(f) of the Regulation, it will be assumed that the mean predetection background noise level should be determined from an energy average of the levels observed over a sampling period of at least 20 seconds. The expected statistical accuracy of a predetection background noise sample, measured in this fashion, is discussed in more detail in Appendix B.

2.2.2 Measurement of Postdetection Background Noise

The postdetection noise floor could ordinarily be read directly on the output display device (i.e., meter, graphic recorder, oscilloscope, or line printer) in the absence of any input signal. In this case, the system sensitivity, following the signal detector, would be set to exactly the same value as for analysis of the aircraft noise data.

The general characteristics of, and methods for measuring, background noise have now been defined. The next step is to examine how errors introduced by background noise can be corrected for in aircraft noise measurements. For an initial approach toward developing such correction methods for background noise, it will be desirable to define an overall background noise level as an envelope of the two types; pre- and postdetection background noise. This envelope, signified in Figure 6 by the heavy dashed line, represents the maximum value of each of these two background noise components and will be identified from here on as simply the background noise.

2.2.3 Simple Test to Distinguish Types of Background Noise

The two types of background noise defined at the beginning of this section may be distinguished by the following simple test. The analyzer gain, just prior to detection of the signal, is increased by, say, 3 dB, while the recorded background noise is being observed at the analyzer output. If the analyzer output also increases by essentially the same amount, it can be assumed that the noise is acoustical or electrical predetection background noise which adds on an energy basis, to the true signal. (In the unlikely event that both the true and background signals are pure tones of exactly the same frequency, the two signals will add, algebraically, to a total value greater or less than either component, depending on their relative magnitude and phase.) If the analyzer output does not increase, the noise is postdetection background noise and represents the analyzer noise floor. If the analyzer output increases somewhere between 0 and 3 dB, the two types of background noise have nearly the same level and one is observing a transition from the non-additive postdetection noise floor to the additive predetection background noise.

3.0 BACKGROUND NOISE CORRECTION METHODS - JET AND LARGE PROPELLER DRIVEN AIRCRAFT

Consider, for now, only correction methods required by Appendix A of the Regulation for jet and large propeller driven aircraft. Assume that the aircraft flyover noise time history, including errors introduced by the background noise has been reduced to a spectral time history in the form of 24 one-third octave band levels at preferred frequencies from 50 to 10,000 Hz, defined at one-half second intervals over the duration of the aircraft flyby. Further assume that the mean background noise level has been measured as specified in the preceding section. Alternate approaches to correct for this background noise are outlined in this section.

3.1 General Approach Currently Defined by the Regulation

Following Paragraph A36.5(d)(3) of the Regulation,[1] the 24 levels representing the mean background noise level spectrum are compared, band by band, to each one-half second spectrum of flyover data. Under the current regulation, the sound pressure level in each one-third octave band of the flyover data, within the 10 dB down period, must exceed the corresponding mean background noise level by at least 5 dB or "be corrected under an FAA approved method" in order to be included in the computation of the aircraft EPNL value. However, if there are no more than four such bands which "violate" this 5 dB signal-to-noise criteria in any spectrum within the 10 dB down period used to determine EPNL, these bands can be simply excluded and the PNLT time history and corresponding EPNL determined without the use of any background noise correction process. Explicit definition of potential "approved methods" that are employed when this latter approach is not followed is, of course, the objective of this report.

It should be noted that the exclusion of up to four bands, as allowed by the Regulation, is partly self-compensating if no background noise corrections are made to any of the other bands. ("Exclusion" means that the violating bands are not included in the PNLT computation.) That is, if some bands are excluded because of their near proximity to the background noise, the measured aircraft signal level for some of the remaining nonviolating band levels would probably be higher than the true level due to augmentation by energy addition of the background noise. This would compensate, in part, for the reduction in PNLT due to exclusion of up to four violating bands. Of course, a lower PNL would be achieved by first applying, to all 24 bands, an energy subtraction of the background noise and then excluding those "corrected" bands that were still within 5 dB of the background noise level. However, it is our belief that this latter procedure would not be consistent with the intent of the current Regulation proviso for background noise corrections since it would result in a final EPNL value consistently below the true value.

3.2 Specific Approaches to Background Noise Corrections

A review of background noise correction procedures for aircraft noise measurement, which have been published by Federal agencies, manufacturers, and consultants, reveals two extremes. The general features of these procedures are summarized in Table I. At one extreme, energy subtraction techniques are used to subtract out background noise for all bands under the assumption it is always energy-additive to the true signal, while at the other extreme, extrapolation is used to fill in missing or violating (level $\leq$ 5 dB above background noise) bands and it is assumed that any signal above the background noise is the true signal. The former process is equivalent to recognizing only predetection background noise, while the latter process might be described as equivalent to recognizing only the postdetection background noise floor.

Even when the background noise levels are satisfactorily defined, and the measured data are properly reduced to the required 24 one-third octave band values for each one-half second, and a background noise correction procedure is available, there are still conflicting paths facing the analyst in determining EPNL. Some of the considerations that create this conflict are:

- Should any correction procedure for background noise be applied to aircraft flyovers that have no single one-half second spectra with more than four violating bands?
- What difference does it make to EPNL whether corrections for background noise are made or not?

Table I

Review of General Features of Published Background Noise Correction Procedures

Reference	Source*	Feature Incorporated (See Code)						
		A		B	C	D	E	F
		Time	Freq					
6	FAA	No	Yes	No	No	No	No	Yes
7, 11	SAE	No	Yes	No	No	Yes	No	No
8	DOT/TSC	No	Yes	No	No	Yes	No	Yes
9, 10	NASA Dytec Douglas	No	Yes	No	No	Yes	No	No
12	Boeing	Yes	Yes	?	Yes	No	Yes	No
13	BBN	No	Yes	No	No	No	No	Yes

Code of Correction Method Features

A ----	Extrapolation in Time or Frequency
B ----	Explicit Recognition of Both Types of Background Noise (i.e., Pre- and Postdetection)
C ----	Requires Source Distance Information
D ----	Uses Energy Subtraction
E ----	Requires "Source" Spectral Directivity Assumptions
F ----	Uses a Specific dB/Octave "Roll-Off" Assumption for High Frequencies

*The attribution of these procedures to specific sources is based only on available published reports and is not intended to represent them as officially adopted procedures for any organization.

- If some one-half second periods have more than four bands in violation, and some less, should corrections be made only to the one-half second levels with more than four violations? Or all time intervals?
- Is the 10 dB down duration time determined before or after the background noise correction is made?

Many aircraft meet the noise certification requirements of the Regulation by only a fraction of a decibel. Thus, proper resolution of a choice between these alternative background noise correction processes is necessary to retain the credibility of the regulatory process, since the corrections themselves can differ by as much as a decibel. The problem is how to essentially remove background noise contributions in an unambiguous but simple way and thus determine the proper aircraft noise levels as if background noise were not present. To be avoided are procedures which either consistently overcorrect by lowering the PNL, PNLT, and resulting EPNL below the true aircraft noise levels free of background noise, or consistently undercorrect and penalize the aircraft noise levels unduly for the presence of background noise. Based on the following review of existing methods, and application of the methods to two representative aircraft signatures, a detailed correction procedure is described which attempts to resolve these problems to the extent possible and is thus recommended for consideration as the official FAA approved procedure.

3.2.1 Application of Band Deletion Provisions of Current Regulation

The FAR Part 36 procedure for considering background noise has already been described in the preceding section. The band deletion part of this procedure consists of simply excluding from PNL and PNLT computations those bands that do not exceed the corresponding mean background sound pressure level by at least 5 dB. The exclusion is limited to a maximum of four bands in any one-half second spectrum within the 10 dB down time. If any spectrum in the 10 dB down time has more than four bands within 5 dB of the background noise, computation of EPNL is prohibited. The following is an analysis of the effect of applying this band deletion approach on typical aircraft noise spectra.

Figure 7 shows representative takeoff and approach spectra for 727 and 707 aircraft (at PNLTM) at locations approximating FAR Part 36 certification positions. These spectra were obtained from the aircraft noise measurements at LAX described in more detail in Appendix A. Data from a microphone position 10 meters above the ground were used to minimize ground reflection effects for this background noise study. The four selected spectra represent a wide range of aircraft characteristics; the measured 727 takeoff spectrum was dominated by jet noise at low frequencies, while the measured 727 spectrum on approach showed turbomachinery noise around 2000 to 4000 Hz. The measured 707 spectra was dominated by turbomachinery noise for both takeoff and approach.

To evaluate application of the band deletion process, an average background noise signature was measured when no aircraft were present. Then, for each aircraft signature, this background noise was artifically increased in level uniformly at all frequencies and one-third octave bands of the aircraft flyover spectrum progressively deleted as they began to fall within 5 dB of this hypothetical background noise level. The actual measured background noise spectrum is also shown in Figure 7.

The result of excluding bands for the four spectra of Figure 7 is shown in Figure 8. Since the bands contributing to the tone correction were not deleted, the change in PNL is also equal to the change in PNLT. Figure 8 intentionally shows a more severe example of band deletion than wold be allowed by the Regulation. The figure indicates that the reduction in PNL for the exclusion of four bands as permitted by the Regulation would probably not exceed about 1 dB, and would most likely be less than 0.5 dB for most aircraft. The contribution of the background noise to the remaining bands was considered only briefly. For the worst case, corresponding to the 727 takeoff spectrum, (curve a in Figure7), removing the energy of the background noise for the remaining 20 bands, after four were deleted, would reduce the PNL by less than 0.3 dB.

While these results are unique to the aircraft and background noise spectra considered, the plot is believed to adequately represent the worst case for the sensitivity of PNL/PNLT to the number of bands excluded. The change in PNLT in Figure 8 is greater than the corresponding change in EPNL for a complete

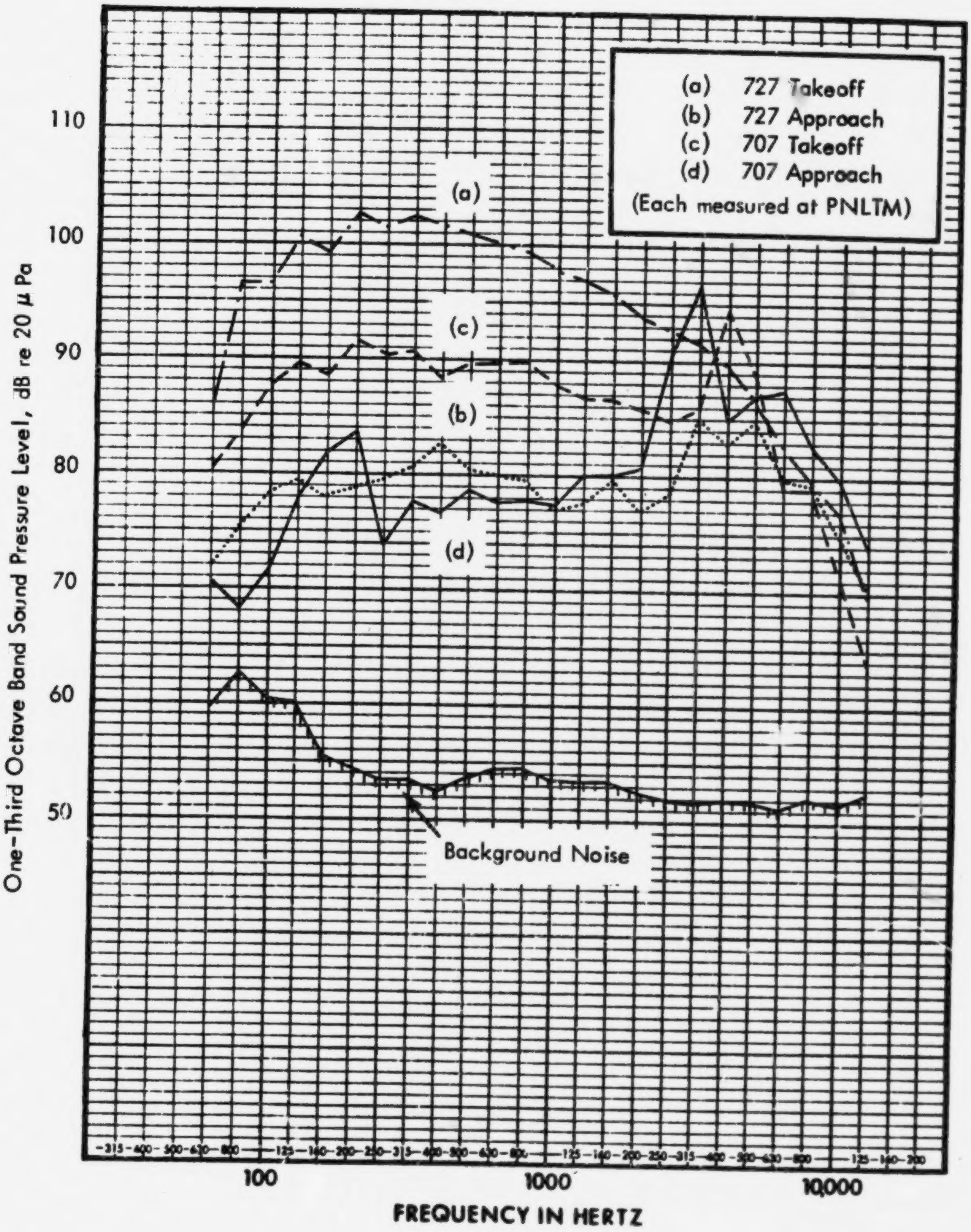


Figure 7. Representative Spectra Used to Demonstrate Effect of Deleting Bands Nearest to Background Noise Spectrum for Computation of PNL

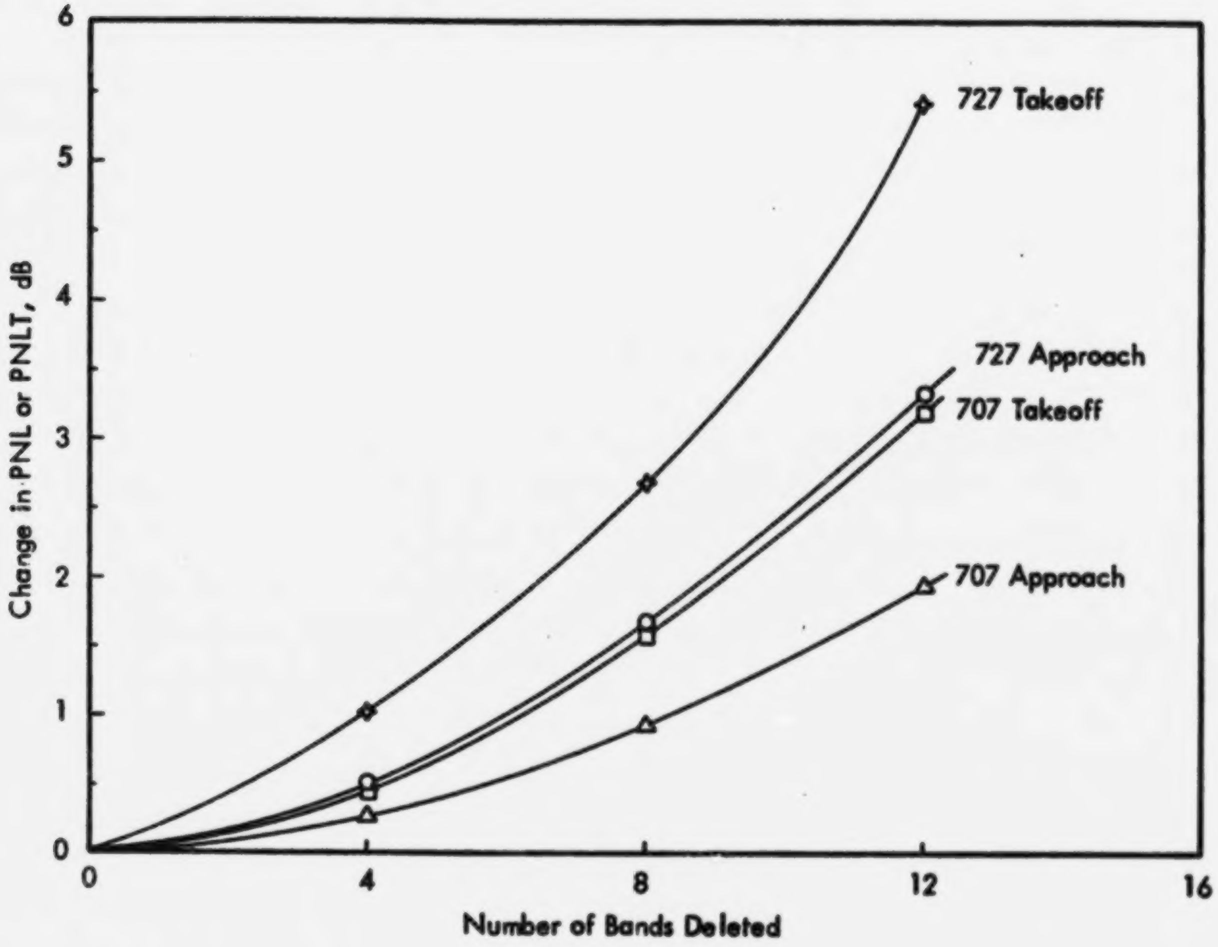


Figure 8. Effect on PNL or PNLT of Deleting Bands for Aircraft Spectra in Figure 7

PNLT time history, since most of the spectra at each one-half second in the 10 dB down period would have less reduction in PNLT than indicated by Figure 8 (i.e., fewer bands would be deleted). Nevertheless, the representative spectra of Figure 7 and the corresponding results of band deletion shown in Figure 8 do provide a framework to examine the relative accuracy of applying this simple correction procedure. The other correction procedures, considered in the following paragraphs, take a more positive approach by providing some means to replace the missing or "violating" bands with estimated signal levels approximately free of background noise. For convenience, the methods are identified by the organization(s) publishing the source documents from which the details were drawn. This identification is not intended to imply that these are officially adopted methods for any organization.

3.2.2 FAA Correction Procedures

Two references to FAA studies of background noise corrections were examined.[6,7] The method outlined in Reference 6 was used to improve the data quality in a particular aircraft noise measurement comparison program. The method is used to apply background noise corrections to high frequency bands in only the PNLTM spectrum. First, this measured spectrum is corrected for differences between "as measured" and reference weather-sensitive air absorption losses. Then a slope of -20 dB per octave is used to estimate missing band levels at the high frequencies using the closest lower frequency band level presumed free of background noise effects. However, no specific criteria is stated for a signal-to-noise-ratio for "background noise free" bands. To facilitate an evaluation of this method, a 5 dB signal-to-noise ratio criterion was assumed for the analysis to be discussed later in this report. The other FAA study (Reference 7), reports one background noise correction procedure proposed by FAA which is still under development. This method is similar to that in a draft SAE procedure (ARP 796)[11] except for the relative signal-to-background noise levels at which different actions are required, i.e.,

1. No change in measured bands which were at least 10 dB above the background noise.
2. Energy subtraction for measured bands which are 5 to 10 dB above the background noise.

3. Extrapolate in frequency, to replace all bands less than 5 dB above background noise by (a) using a linear extrapolation of the nearest three valid "as measured" signal bands that are free of pure tones, or (b) using a linear extrapolation based on high frequency spectrum roll-off rates measured near the source and then extrapolated to the appropriate sound propagation distance to determine the effective roll-off rate at the measurement position.

3.2.3 DOT/TSC Correction Method (Reference 8)

The method was applied only to high frequency bands for which it was apparently assumed that the background noise corresponded to the postdetection noise floor and did not contribute to the measured levels. A slope correction method for bands within 5 dB of the noise floor was used to replace up to 7 bands in each one-half second spectra. Prior to computing PNL, a slope of -6 dB per octave was used to determine the replacement value of these "violating" or missing bands using the adjacent band levels.

3.2.4 NASA/Dytec/Douglas Correction Methods (References 9 and 10)

This correction procedure appears to assume background noise is always energy additive to the true spectrum. The procedure calls for:

1. Energy subtraction for measured levels within 5 dB to 10 dB of the background noise (no correction for bands more than 10 dB above the background noise).

2. Exclude from PNL calculations those measured bands less than 5 dB above the background noise.

As discussed earlier, the concept of always subtracting the background noise from the measured bands on an energy basis, and excluding bands which do not exceed the background noise by more than 5 dB, can be expected to provide the lowest possible (and, in our opinion, unrealistically low) PNL value. This expectation was borne out by the evaluation reported at the end of this section.

3.2.5 Proposed SAE Method (Reference 11)

This is a proposed revision of SAE ARP 796 which has been undergoing changes since 1973 (latest available update, January 1976). The method recognizes only the predetection (acoustic) background noise involving energy subtraction of the background noise for all bands. It is similar to the method in Reference 7, but uses different criterion levels for the required signal to background noise ratio when applying corrections.

1. No change in measured bands 15 dB above the background noise;
2. Energy subtraction for bands 3 dB to 15 dB above the background noise (Item a of para. 5.3.3, Ref. 11);
3. One of the following two options for bands within 3 dB of the background noise:

Method A	Exclude them with no substitution (Item b.1 of para. 5.3.3, Ref. 11); or
Method B	Extrapolate, in the frequency domain, the "as measured" levels (i.e., before any adjustment to standard weather conditions), using the nearest three valid bands (Item b.2 of para. 5.3.3, Ref. 11).

3.2.6 Boeing Method (Reference 12)

This method appears to recognize only the postdetection background noise floor, since it does not include any energy subtraction corrections. However, no specific definition is given for just what constitutes the "background noise" levels to be used for purposes of data analysis. The method is based upon applying one of two correction equations which require knowledge of source distance, and "as measured" weather conditions; the corrections are applied to "as measured" spectra before adjusting for nonstandard weather. The first equation below (the preferred method), is applied at a given frequency, to extrapolate, in the time domain, from a valid band level available at one time period to estimate a missing band level for an adjacent time period. The method is based on assuming the source is nondirectional, and applies the following extrapolation equation:

$$SPL'_{i,j} = SPL_{i,j-1} - 20 \log_{10}\left(\frac{d_j}{d_{j-1}}\right) - \left(\frac{d_j - d_{j-1}}{100}\right) A_i \quad , \text{dB} \qquad (2)$$

where

$S'_{i,j}$	is the extrapolated level of a noise-contaminated (missing) band at the i-th frequency and j-th time, dB
$S_{i,j-1}$	is the previous (j-1) noise-free band level at this i-th frequency, dB
d_j and d_{j-1}	are the distances to the source at the j and j-1 time intervals, meters
A_i	is the appropriate atmospheric absorption coefficent for the i-th frequency band, dB/100 m

Using the band level from the last (j-1) time period for which a valid level is available, this expression simply extrapolates this level to the j-th time period by accounting only for the change in spreading and atmospheric absorption loss.

The second equation, used only if no band level at a particular frequency is ever above the noise floor during an aircraft flyby, employs frequency extrapolation from the next lower valid frequency band by assuming a flat spectrum back at the source (i.e., a source spectrum for which all band levels are equal). That is:

$$SPL'_{i,j} = SPL_{i-1,j} - \frac{d_j}{100} \cdot (A_i - A_{i-1}) \quad , \text{dB} \qquad (3)$$

and the variables are as defined above. This is similar to, but more conservative than, the second alternative approach to frequency extrapolation proposed in the FAA procedure as outlined earlier in paragraph 3.2.2, item 3.

3.2.7 BBN Method (Reference 13)

This method provides a general approach for determining "missing band levels" for any reason and is used here to replace bands within 5 dB of the background noise.

1. For missing or "violating" high frequency bands, extrapolate using the nearest two valid band levels, but ensure that the absolute value of the negative slope is 18 dB per octave or greater;

2. For missing or violating mid-frequency bands surrounded by valid bands, interpolate from the valid bands on each side;
3. For missing or violating low frequency bands, set the levels equal to the nearest valid band level, i.e., assume a flat spectrum at lower frequencies.

3.3 Relative Merits of Alternate Correction Methods

As the final step toward development of a possible standard "FAA approved" method, consider the relative merits of the various approaches to background noise corrections, most of which were described in the preceding paragraphs.

The various background noise correction methods can be summarized as follows:

1. Do-nothing approach (make no corrections).
2. Delete "violating" bands without replacement (see paragraphs 3.2.1, 3.2.4, and 3.2.5 for example applications of this approach).
3. Extrapolate in the frequency domain with a fixed slope to replace missing or "violating" bands which fall within a specified criterion level relative to the background noise (see paragraphs 3.2.2, 3.2.3, and 3.2.7).
4. Similar to method 3, except apply a simple extrapolation technique to the valid frequency bands remaining in a given spectra (see paragraphs 3.2.5 and 3.2.7).
5. Extrapolate in the time domain using a fixed time history model such as the nondirectional source used for the Boeing method (see paragraph 3.2.6).
6. Similar to method 5, except apply a simple extrapolation technique to the remaining adjacent and valid time samples.
7. Apply an energy subtraction of the background noise when the measured signal plus background noise falls within a specified range above this noise (see paragraphs 3.2.2, 3.2.4, 3.2.5).
8. Combinations of the above.

3.3.1 Do-Nothing Approach

A negative or null approach to background noise corrections is not acceptable. The resultant error in a measured noise certification level would be undefined and subject to considerable variation from test to test, thus making a shambles of the integrity of the Regulation. Hence, one of the questions posed earlier - should a correction be made at all - is answered positively with a definite yes.

3.3.2 Delete "Violating" Bands Without Replacement

As shown earlier in Figure 8, this approach, presently allowed by the Regulation for up to four bands in any one spectrum, can result in an error of the order of -0.5 ±0.5 dB in the calculated PNL. As mentioned in Paragraph 3.2.1, this error is at least partly compensated for by not correcting the remaining measured bands for the residual effects of background noise. However, as will be shown later, this band deletion correction method is one of the least accurate methods. Therefore, it is not likely to be recommended as a suitable candidate for an official "FAA approved" correction method. However, since the residual error in EPNL values may, in fact, be quite small, this method deserves more careful consideration to judge its suitability for retention as the simple default procedure currently provided for by the Regulation.

3.3.3 Extrapolate in Frequency with Fixed Slope

This simple "band shaping" procedure is easily applied during the data reduction process to replace missing bands or bands which violate the minimum allowable margin between the measured aircraft signal and the background noise. However, since this method applies a single fixed slope to the measured spectrum, it can only hope to approximate the actual value of the missing bands. The true slope of an aircraft noise spectrum at high frequencies varies substantially as a function of engine type and power setting, propagation distance and weather. The influence of these factors on the spectrum shape is illustrated in Figures 9 and 10.

Figure 9 shows the general range of spectrum shapes at PNLTM for takeoff (Figure 9(a)) and approach (Figure 9(b)) for several aircraft types. The spectra were obtained from the measurement program described in Appendix A and

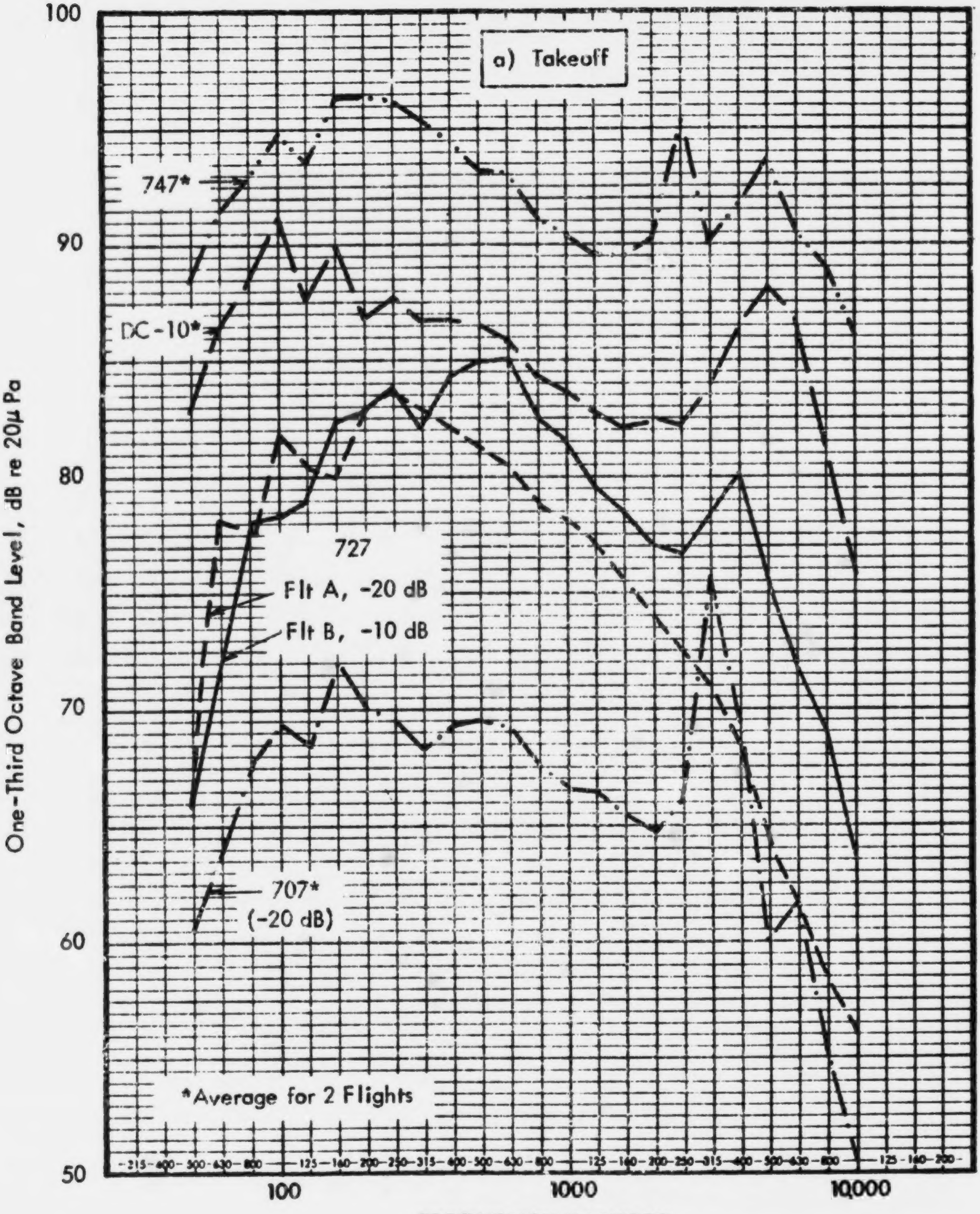


Figure 9. PNLTM Spectra Normalized to 300 m, 25°C, 70% RH - 10 m Microphone over Hard Ground (Some Spectra Displaced Vertically by 10 or 20 dB, as Noted)

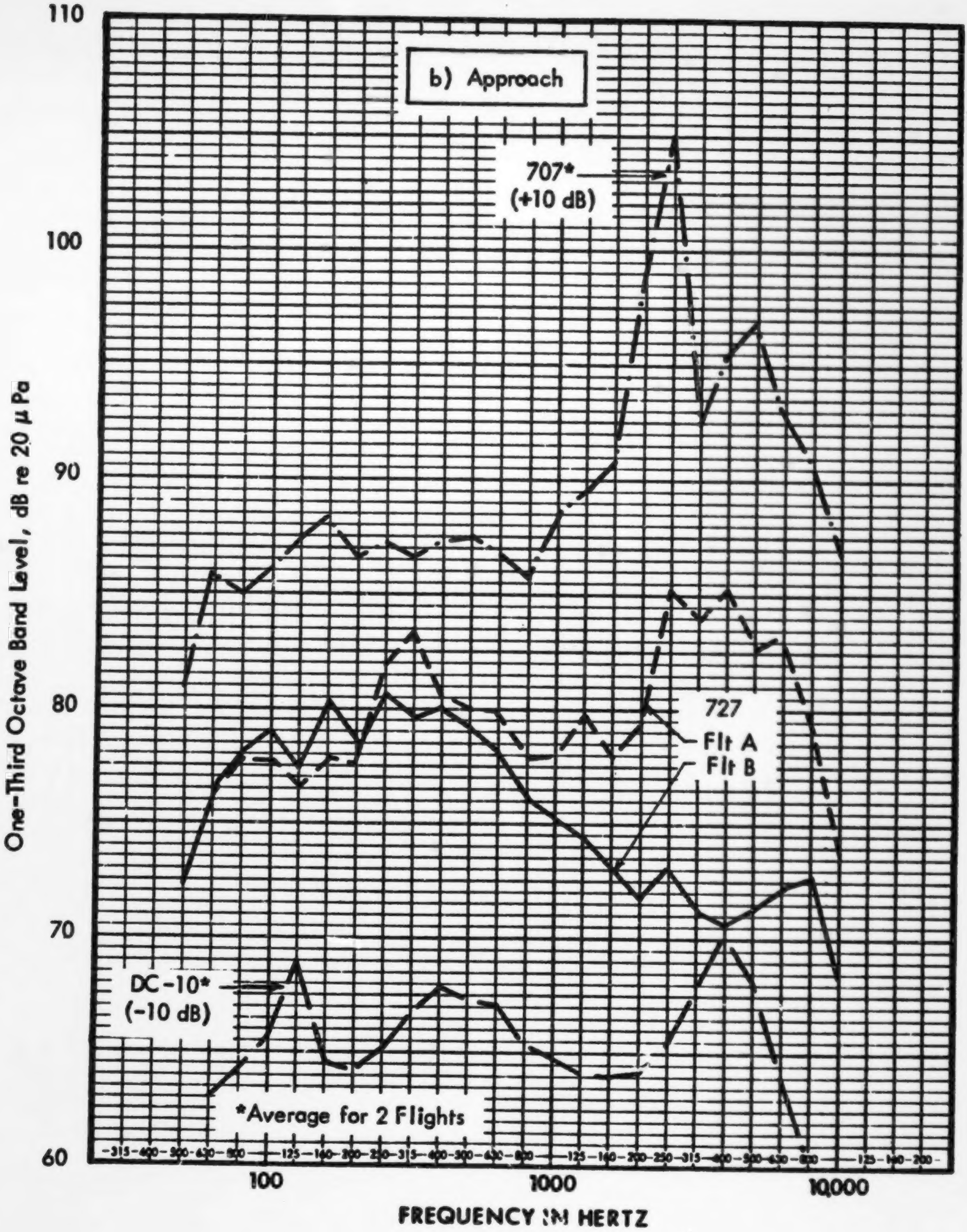


Figure 9 (Concluded)

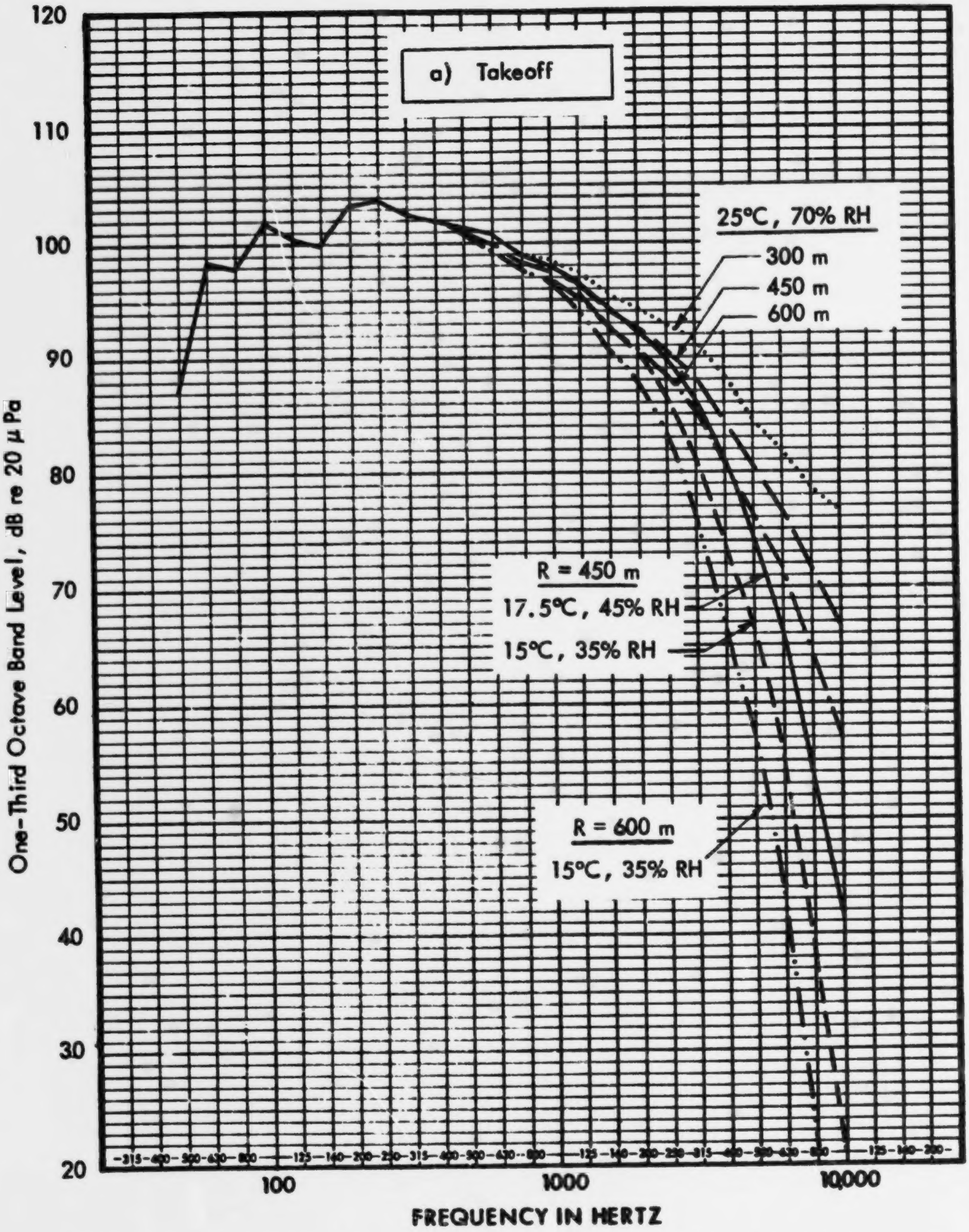


Figure 10. Estimated Variation in PNLTM Spectra for 727 (from Figure 9) Due to Changes in Propagation Distance (R) and Weather. (Change in Spreading Loss Not Included)

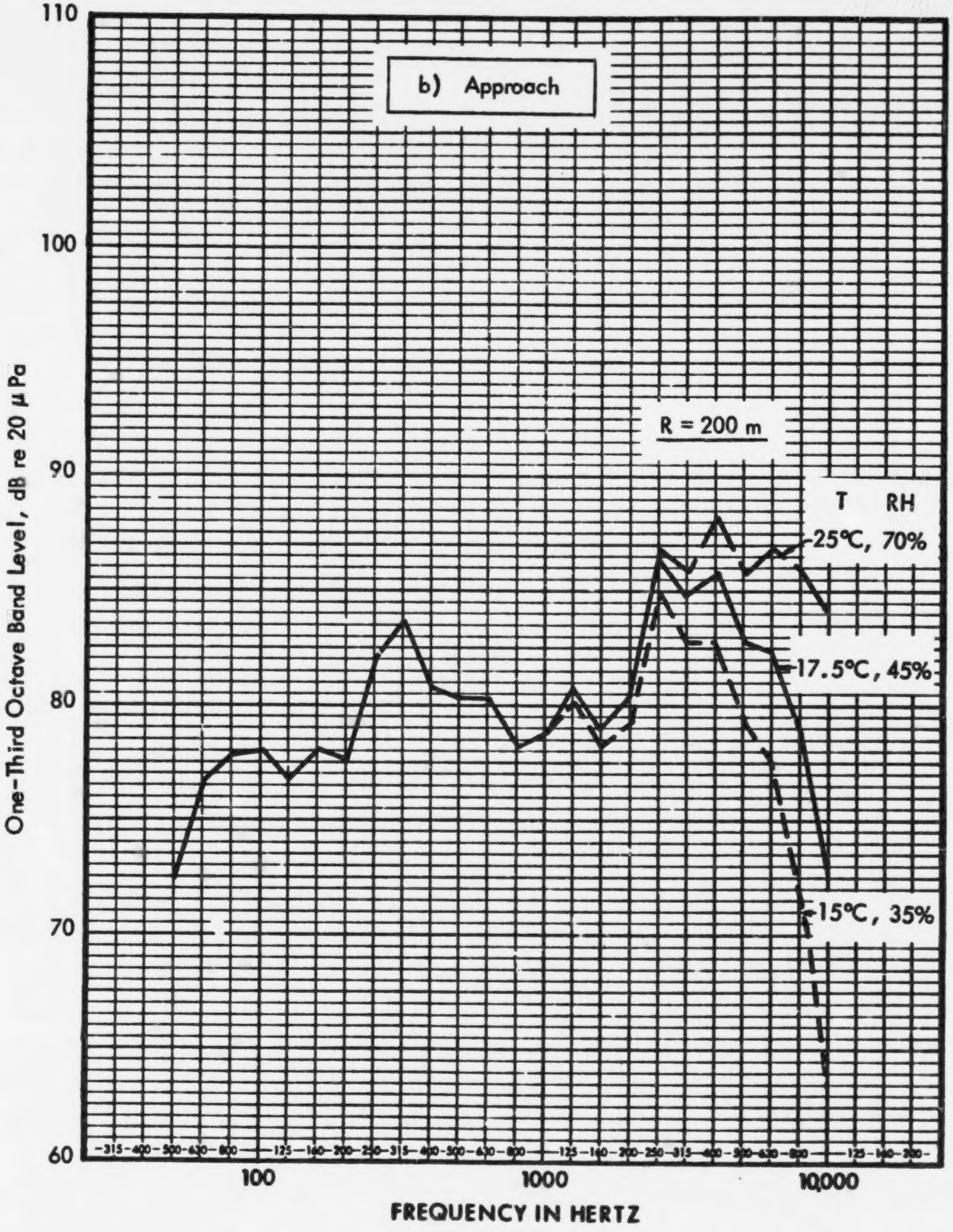


Figure 10 (Concluded)

have been normalized to a propagation distance of 300 m and to 25°C and 70% relative humidity using SAE ARP 866A.[14] For convenience in presentation on these figures, some of the spectra are based on an average of two separate flights of different aircraft. The two sets of measurements agreed with each other, after normalization, within an average absolute difference of about 1.6 dB over all 24 bands. The two 727 spectra are considered approximately representative for treated and untreated nacelles.

The adjustments to the raw data utilized for these figures, to account for differences in atmospheric absorption loss due to off-reference weather and propagation distances, were small - the average adjustment at 4 kHz was about ± 1 dB.

In the frequency range of 5 to 10 kHz, where linear extrapolation of the band levels is most often required for this method, those normalized spectra exhibit a range of slopes varying from -7.5 to -16 dB/octave for takeoff spectra and -3 to -13.5 dB/octave for approach spectra. (The average is about -10 to -12 dB/octave for both conditions.) Thus, even for spectra normalized to a standard distance, temperature and humidity, high frequency roll-off slopes vary substantially among the various aircraft types and operating conditions (i.e., takeoff or approach engine power).

This does not allow for any additional variation in high frequency roll-off slopes that may occur when spectra at other than the time of PNLTM are considered. It is at these times, of course, when frequency extapolation is most likely to be required.

To explore this point, the range of high frequency roll-off rates over the entire time history for many of the flybys measured according to Appendix A were examined. (See multiple time and frequency plots in Appendix A of Volume I of this series of reports on Correction Procedures for Aircraft Noise Data.)[15] In general, the high-frequency roll-off rates of the unnormalized spectra during the "10 dB down" period are quite similar to the roll-off rate at PNLTM, except when turbomachinery-generated pure tone components are dominant. Thus, with the latter exception, the range of slopes for the high frequency portion of the spectra in Figure 9 are considered representative of the range to be expected in practice, due solely to differences in aircraft type and operation, disregarding any differences due to atmospheric absorption at off-reference conditions.

Figure 10 examines this latter point by showing how the normalized PNLTM spectra for one of the 727 aircraft, given in Figure 9, changes when the reference conditions change. For convenience, frequency-independent changes in inverse square-law spreading loss for different propagation distances are ignored. Figure 10(a) shows the case for the takeoff condition where the propagation distance (R) varies over a range of 300 to 600 m - a range that could be encountered in a takeoff certification measurement (not necessarily for the 727 aircraft, however). Also shown is the effect of changing the atmospheric conditions from a standard 25°C and 70% relative humidity to an extreme value (15°, 35% RH), corresponding approximately to the limit allowed by the Regulation for certification measurements (i.e., absorption coefficient at 8 kHz less than 12 dB/100 m),[1] and to an intermediate value (17.5°C, 45% RH). The wide range of high frequency roll-off rates is quite apparent.

Figure 10(b) shows the case for a 727 approach PNLTM spectra (drawn from Figure 9(b) - Flight A) with an approximate propagation distance of 200 m and three different weather conditions. Again, the variation in high frequency roll-off rate is substantial.

Table 2 summarizes the values of high frequency attenuation rates found in Figures 9 and 10 over the highest frequency octave from 5 to 10 kHz. It is important to note that these attenuation rates are predicted values, based on application of single frequency atmospheric attenuation coefficients (from SAE ARP 866A) for each filter band. This method does not account for errors introduced by the effects of finite sidebands for non-ideal filters employed in normal aircraft spectrum analysis. This topic, as it relates to background noise corrections, is to be considered in another report in this series on correction procedures for aircraft noise measurements.

In summary, considering the very wide range of predicted high frequency attenuation rates indicated by Figures 9 and 10 and Table 2, it is obvious that the application of any single value, such as required by the correction method considered here, is subject to large errors. Thus, extrapolation in frequency with a fixed slope is not recommended for consideration as the sole basis for an "FAA approved" correction method for background noise problems. However, it will be shown later that this technique, when incorporated with other features, does provide an accurate basis for background noise corrections.

Table 2

Range of Predicted High Frequency Attenuation Rates, in dB/Octave from 5 to 10 kHz, for PNLTM Spectra for Various Aircraft, Operating Conditions and Weather

Aircraft Type	Operation	Propagation Distance m	Temperature/Relative Humidity		
			25°C/77%	17.5°C/45%	15°C/35%
747	Takeoff	300	-7.5*		
DC-10			-16		
707			-15		
727			-8 to -11		
		450	-15	-34	-45
		600	-20		-54
DC-10	Landing	300	-12		
707			-9		
727(B)			-3		
727(A)			-13.5		
		200	-3	-13	-20

* dB per octave

3.3.4 Extrapolate, in Frequency with a Slope Based On The Available "Nonviolating" Bands

This method involves extrapolating the available valid band levels adjacent to the missing or violating bands using the slope defined by these valid bands. Clearly, this method would tend to minimize the error of the previous method described in the preceding section by allowing the extrapolation slope to vary according to the valid measured levels. Nevertheless, this method is not without problems.

Examination of Figures 9 and 10 shows that this technique would be quite difficult to employ, reliably, at the low frequency end of the spectrum where spectrum slopes often vary substantially from one band to the next. At the high frequency end, the technique is more promising, especially for takeoff spectra which tend to exhibit a pattern of a more nearly constant slope. Even here, however, one must be prepared to accept a very conservative overestimate of a missing band or bands since, in many cases, the negative spectrum slope is actually decreasing more and more as frequency increases over the last one or two octaves. Also, just as for the low frequency end, some of the spectra (i.e., those for which turbomachinery pure tone components are very apparent) show erratic slopes at the high frequency, making it difficult to extrapolate reliably with any type of simple linear extrapolation rule.

In summary, if it were not for the limitations associated with erratic or gradually changing spectrum slopes, this method would have definite promise for application to supplying missing band levels. However, these limitations are considered sufficiently important to prevent this method from being considered as a strong candidate for a universally accepted "FAA approved" method.

3.3.5 Fixed Extrapolation Model in the Time Domain

This method, outlined previously in Section 3.2.6, applies a simple nondirectional source model for extrapolating, in the time domain, to supply missing or "violating" bands which fall below some signal-to-noise criterion level. This method has the advantage of being readily applicable to the "as measured" data without any assumptions about frequency spectrum. Two major disadvantages are: (1) application of the method requires full knowledge of the aircraft position at each moment in time (while this must be known for other purposes of aircraft noise data analysis, it is not required for any other background noise correction method); and (2) the correction method will tend to be conservative since directivity effects are ignored. This last point is illustrated in Figure 11. This compares the measured and predicted time history of the one-third band level at 3150 Hz relative to its maximum value, for a 727 on approach. Three predictive models for the sound level observed near a moving monopole source are illustrated. The "static" model is the simple one - described earlier in Section 3.2.6 - it predicts the change in level solely on the basis of changes in spreading and absorption loss as the source-receiver path length changes. The "kinematic" model includes the retarded time effect due to the finite speed of sound while the "acoustic" model is the exact solution for this problem, which also accounts for convective amplification of the source output due to its motion. A more complete discussion of these models is given in Appendix D.

Clearly, the simplest static model shows very nearly the same rate of change in level, as the more sophisticated predictive models, except right near the peak of the time history curve. Since this correction method is essentially based on using this predicted rate of change in level with time as the basis for extrapolation, the simple static model, as defined by the first equation in Section 3.2.6, is quite adequate for application to this extrapolation method.

Consider, now, how successful this method is likely to be. According to Figure 11, the simple time history model fits the actual measured data quite well for a portion of the time history near the maximum values. However, near the "10 dB down" times for the measured data, although the predicted rate of change of level for each one-half second is similar to that for the observed rate, the absolute levels differ substantially. Thus, the ability of any temporal extrapolation to supply missing bands will vary substantially depending on the starting point for the extrapolation. For example, if only the band levels at the edge of the "10 dB down" period must be estimated by extrapolating, the accuracy will be quite good since the predicted and actual slopes are nearly the same and by starting the extrapolation near the ends of the time history, the decrease in absolute level below that predicted by the static model for the entire time history will be properly accounted

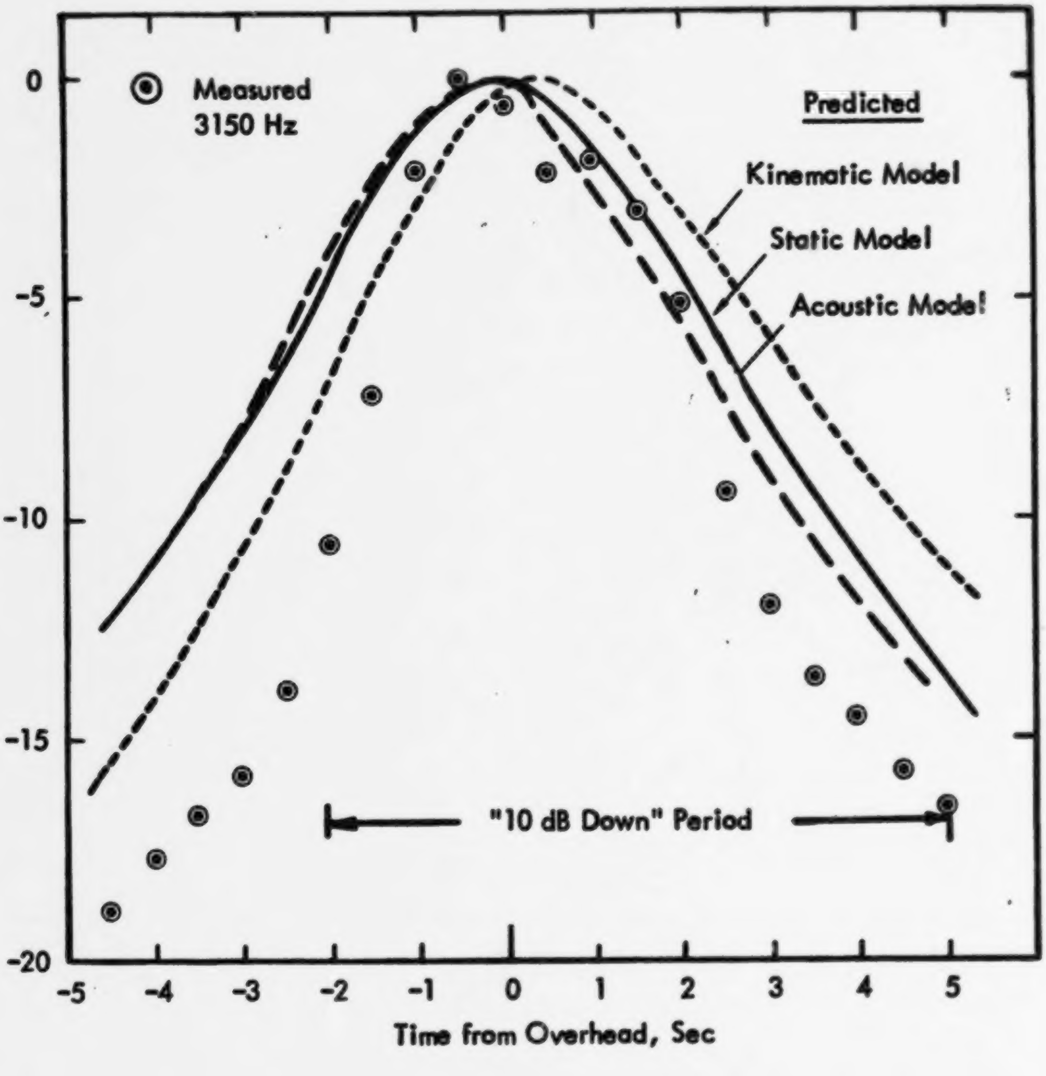


Figure 11. Comparison of Measured Time History of Relative One-Third Octave Band Level at 3150 Hz from 727 on Approach with Values Predicted by Three Different Versions of a Simple Moving Monopole Source Model. (Aircraft Altitude, 127 m, Mach No. = 0.2, Atmospheric Attenuation Coefficient = 1.78 dB/100 m)

for. However, if the starting point for the extrapolation is closer to the peak of the time history, the extrapolated levels can be overstated by 5 to 6 dB.

Another example of temporal extrapolation is illustrated in Figure 12 which shows the measured and predicted time history of relative levels in the 80 Hz band during a 727 takeoff. In this case, the major effect of source directivity is quite apparent - the actual maximum of the time history occurs about 3 seconds after the time of overhead. Thus, as shown by the dashed lines, if it were necessary to estimate all levels less than 10 dB below the maximum by temporal extrapolation, the initial part of the time history would be overestimated by as much as 9 dB. However, the ultimate effect of such a large error on EPNL would usually be small. For example, the sound exposure level of the estimated time history, according to the extrapolation illustrated in Figure 12, is only +0.4 dB higher than the true value over the 10 dB down period. (Note that for both Figures 11 and 12, the 10 dB down period is the true value based on the period between "10 dB down" times on the PNLT time history.)

3.3.6 Extrapolate in Time with a Slope Based on the Available "Nonviolating" Bands

This method is similar to the previous one except that the slope of the temporal extrapolation line is obtained from the slope of a "best fit" curve or line through the available "nonviolating" bands. Examination of the actual time histories in Figures 11 and 12 indicates that this technique might be fairly successful for temporal extrapolation of high frequency bands but the technique would probably often encounter difficulties for low frequency bands - particularly if one wanted to use a simple linear extrapolation line with a constant slope.

A more complete evaluation of this technique was desirable so a collection of time history plots for a number of one-third octave bands from one 727 takeoff have been assembled in Appendix C. The time histories for microphones near the ground surface (actually 1/2 inch above it), at 1.2 m, and at 10 m, have been overlaid for the sake of comparison. Examination of these figures shows that the time histories for the low frequency bands are often quite erratic. This is due, in part, to the effect of local ground reflection at each of the microphone positions. At the high frequency end (i.e., $\geq$ 1000 Hz), the time histories for the 1.2

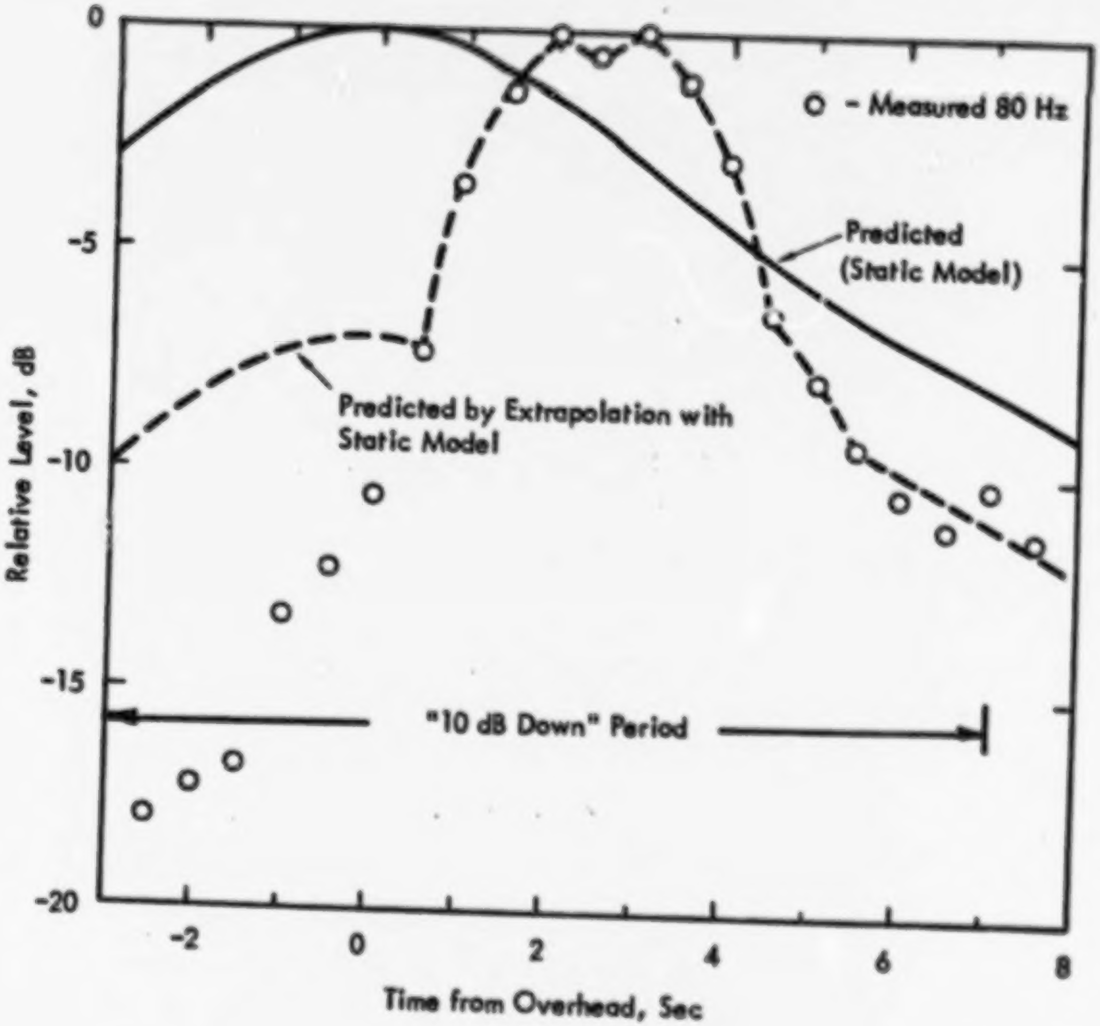


Figure 12. Comparison of Measured Time History of Relative One-Third Octave Band Level at 80 Hz from 727 on Takeoff with Values Predicted by Simple "Static" Model for Moving Monopole Source (Directivity, Kinematic and Acoustic Effects of Motion Ignored). Dashed Lines Designate Predicted Values when Levels Less than 10 dB Below Maximum Must Be Estimated by Using Temporal Extrapolation Based on a Static Model for the Change in Propagation Loss with Time. (Aircraft Altitude 244 m, Speed = 80 m/s, Mach No. = 0.23, Atmospheric Attenuation Coefficient = 0.013 dB/100 m)

and 10 m microphone positions show very close agreement. However, the values for the surface microphone show a consistent decrease, relative to the others, reaching a minimum at about 6300 Hz. This is close to the first frequency (6700 Hz) for destructive interference between the direct and reflected signals for a "surface" microphone diaphragm located 1.27 cm (0.5 inch) above a rigid plane with the incident sound wave arriving vertically. This anomaly could have been essentially eliminated by locating the microphone diaphragm within 0.32 cm (1/8 inch) of the surface).

This form of temporal extrapolation should avoid the error caused by neglecting directivity effects which was inherent in the previous method. However, the method is not without problems in defining, unambiguously, a valid extrapolation line for estimating missing bands. This problem appears to be worst at low frequencies. At high frequencies, providing one is careful to avoid anomalous results due to reflection or refraction at short wavelengths, the method appears to be very promising.

A more detailed analysis of the theoretical time history of sound level observed near a moving monopole source in a uniform, still, lossy medium is presented in Appendix D. Figure 13, from this appendix, shows that for values of the total absorption, A_e, over the slant distance Y to the source path, greater than about 1 dB, the slope of the time history curve tends to be fairly constant for values of a dimensionless time variable τ(= time x source velocity/slant distance) greater than 1. This seems to reinforce the potential validity of using this method for temporal extrapolation of high frequency bands. Unfortunately, there are frequent occasions when a recorded aircraft signal will have no useful signal at all in one or more high frequency bands. In such cases, temporal extrapolation methods cannot be used at all.

In summary, while this temporal extrapolation method is not without problems, it does show promise as a useful technique for extrapolating high frequency bands when sufficient portions of the time history are available to establish the slope of an extrapolation line. One other disadvantage is that this method adds a minor complication in the data reduction process; however, this can be resolved by using simple linear extrapolation algorithms suitable for computer processing.

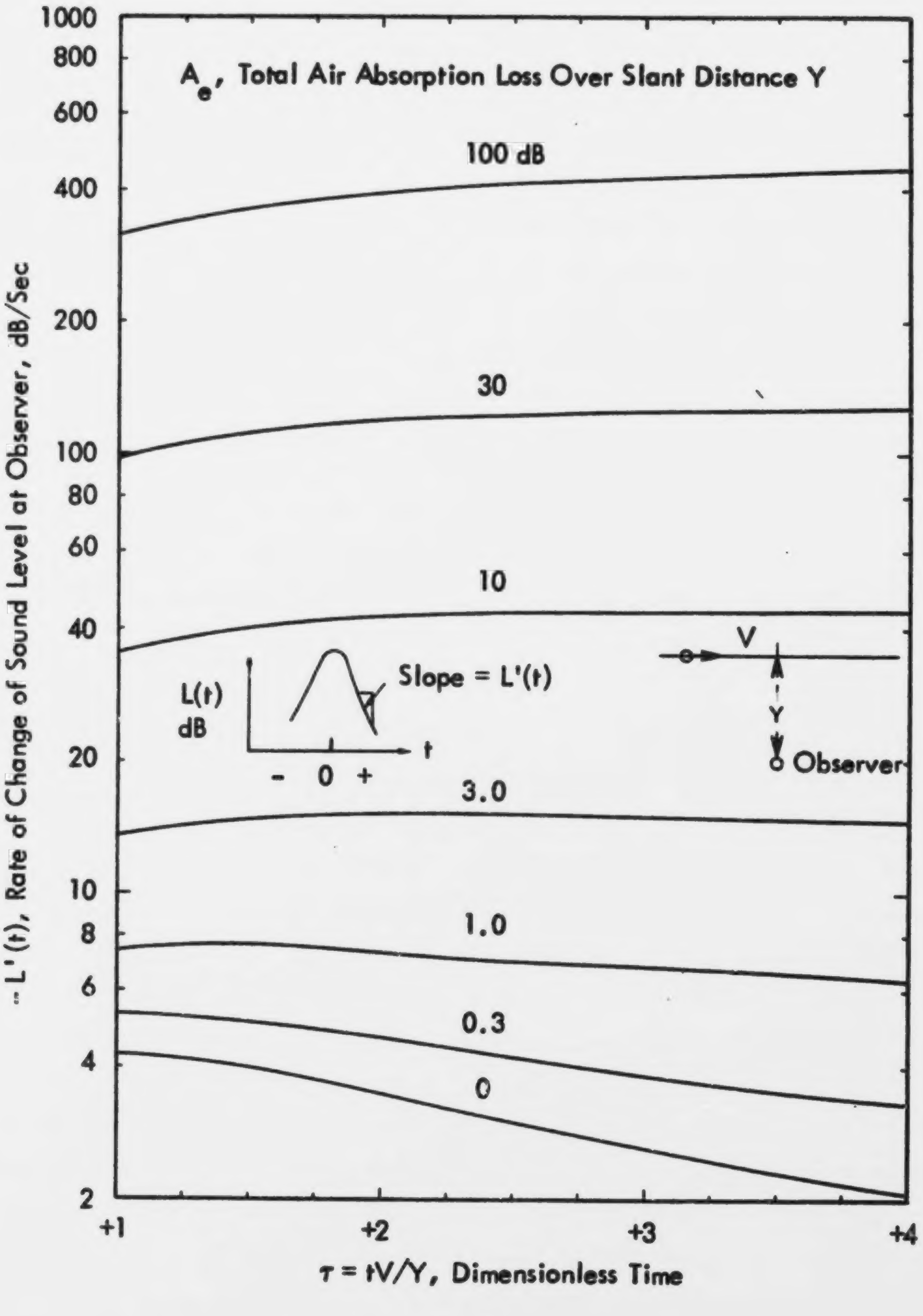
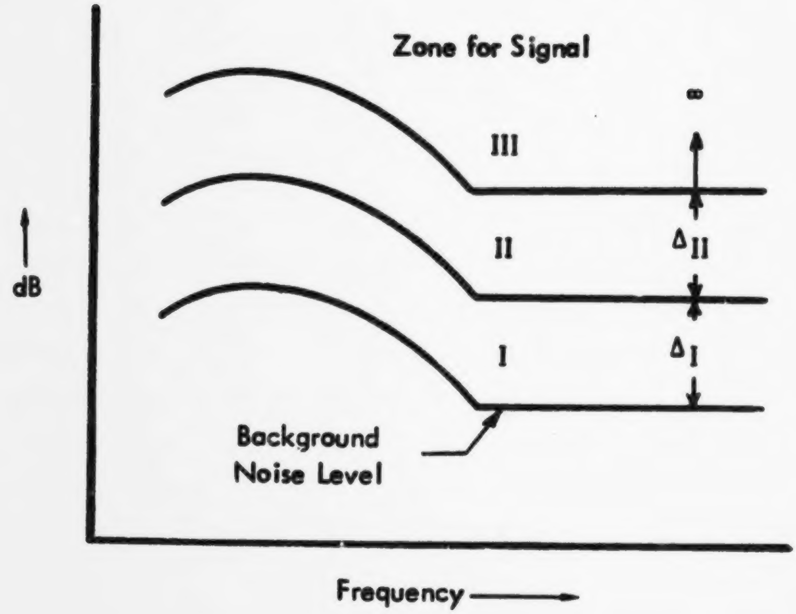


Figure 13. Rate of Change of Level Observed Near Simple Moving Monopole Source in a Uniform, Still, Lossy Atmosphere (See Appendix D for Derivation)

3.3.7 Energy Subtraction Methods

An entirely different approach from the preceding extrapolation technique is provided by the procedure of applying energy subtraction of the background noise. As established at the beginning, this technique is restricted to situations for which the background noise is the predetection energy-adding type of noise. This is nearly always the case at low frequency bands and can occasionally occur for high frequency bands, as illustrated earlier in Figure 6 (see page 15). Thus, the most significant disadvantage of this method is that it requires knowing which type of background noise is present in each band of the total background noise spectrum. Techniques for making this determination were discussed in Section 2.2. The only other presumed disadvantage is associated with the potential error in any one measurement when applying this correction method due to the inherent statistical uncertainty in the usual fluctuating background noise. However, as discussed in Appendix B, when one takes into account that this statistical error is random by nature (i.e., it can be either positive or negative) and one also accounts for the low probability of a substantial residual error from multiple measurements (i.e., more than one band, more than one time segment and more than one flight), the result is a very satisfactory picture for the overall accuracy of the method. In this regard, many of the other correction methods outlined will often consistently over- or under-correct for background noise.

One final important aspect of the energy subtraction method is that a specific criterion must be established for the range of the "as measured" signal-to-noise ratio, in dB, within which this method will be applied. (The measured "signal" consists, of course, of the true aircraft noise signal plus the energy-adding predetection noise.) Figure 14 summarizes the signal-to-noise criteria for the specific methods reported in the literature. It shows that the span of this critical signal-to-noise ratio within which the energy subtraction method is used is from 5 to 10 dB above the background noise for correction methods reported in References 7, 9, and 10 and from 3 to 15 dB for methods reported in Reference 11. The lower limit of 3 to 5 dB is presumably based on the uncertainty in the actual background noise level during the time of the aircraft flyover. However, a more detailed evaluation of this problem, carried out in Appendix B, indicates that a much lower



Ref.	Source	Zone for "As Measured" Signal				
		I		II		III
		ΔI (dB)	Procedure	ΔII (dB)	Procedure	
1	FAR Part 36	5	Delete(1)	∞	None	No Correction In This Zone
6	FAA	5	-20 db/oct(2)	∞	None	
7	FAA	5	Extrapolate(3)	5	Energy Sub.	
8	DOT/TSC	5	-6 dB/oct(4)	∞	None	
9, 10	NASA, Douglas	5	Delete(5)	5	Energy Sub.	
11	SAE (Method A)	3	Delete(5)	12	Energy Sub.	
	SAE (Method B)	3	Extrapolate(3)	12	Energy Sub.	
12	Boeing	?	Extrapolate(6)	∞	None	
13	BBN	5	Extrapolate(7)	∞	None	

Notes

(1) Limit of 4 bands can be excluded from EPNL or FAA approved corrections applied.

(2) Extension of high frequency bands at this slope starting from nearest valid band.

(3) Linear extrapolation in frequency.

(4) Extension of up to 7 high frequency bands at this slope.

(5) Exclude bands within this zone from PNL calculations.

(6) Extrapolate in time (preferred) or in frequency from nearest valid band.

(7) Extend high frequency bands at slope ≤ -18 band/octave and low frequency bands at zero slope.

Figure 14. Criteria for Signal-to-Noise Ratio for Background Noise Correction Procedures

limit to the signal-to-noise ratio is possible for application of the energy subtraction method. Furthermore, it is felt that it is not desirable to have an upper limit on the signal-to-noise ratio span within which background noise corrections should be applied. Even though any energy correction becomes miniscule for a signal-to-noise ratio greater than 20 dB, it is felt that for the sake of consistency and simplicity in data reduction, there should be no upper limit for this signal-to-noise ratio.

In summary, the application of an energy subtraction method for correcting for predetection type of background noise is considered a powerful candidate for an FAA-approved correction method because of its inherent accuracy and relative simplicity for implementation.

3.3.8 Combined Methods

To be complete, the energy subtraction correction method must be combined with one of the extrapolation techniques outlined in the preceding sections to replace or correct missing or violating bands which are masked by the non-additive postdetection background noise floor. The simplest and potentially least accurate choice would be to employ the fixed frequency extrapolation technique discussed in Section 3.3.3. This combination was evaluated in more detail, as will be discussed shortly, and was found to be very satisfactory. Other combinations of correction methods are possible, such as the combined (or alternate) temporal and frequency extrapolation techniques reported in Reference 12.

3.4 Specific Correction Methods Developed for this Report

With the preceding qualitative background as a guide, two slightly different versions of a combination correction method were developed to provide a suitable combination of the best procedures outlined so far. The goal was to arrive at a correction method which would be both accurate and simple.

These methods explicitly recognize the two different types of background noise (energy contributing and masking). The first method, identified as Wyle I, performs energy subtraction at lower frequencies and extrapolation, at high frequencies, to replace measured levels less than 2 dB above the background noise.

The second method, Wyle II, was included to determine the possible improvement over Wyle I of first normalizing the "as measured" spectra to a distance of 60 m (197 ft) and standard day conditions (25^{o}C, 70% RH) before applying any frequency extrapolation.

The specific steps involved in applying these methods can be described as follows:

Wyle Method I

1. Identify the frequency range for which the background noise is predetection noise which adds, on an energy basis, to the measured aircraft noise (see Section 2.2 for a discussion of methods to make this determination). Outside this range, the background noise is the masking non-additive postdetection noise.

2. To correct all measured bands whose center frequency is within the frequency range dominated by predetection background noise, subtract the background noise from the aircraft noise on an energy basis. If the corrected band is more than 10 dB below the "as measured" (uncorrected) aircraft noise level, set it equal to the measured level minus 10 dB. (This is equivalent to limiting the background noise correction to -10 dB whenever the "as measured" aircraft noise level is within 0.46 dB of the background noise level.)

3. The remaining bands fall inside the frequency range of the postdetection background noise. Those bands which are within 2 dB or less of this type of background noise will be identified as "masked" bands. For all other bands in this frequency range, no correction is applied.

4. Replace the identified "masked" bands as follows:

   For the usual case, when one or more adjacent masked bands exist at high frequencies, start at the highest frequency for an unmasked band and replace masked bands at higher frequencies by extrapolation at a rate of -9 dB/octave or, if greater, by the rate corresponding to the slope between the level of the highest frequency unmasked band and the postdetection background noise floor. For masked bands surrounded on both sides (of the frequency axis) by unmasked bands, no correction is required.

Wyle Method II

Steps 1, 2, and 3 are the same as Wyle Method I. Step 4 above is replaced with the following three steps:

4. Normalize the "as measured" spectrum to a standard day (25°C, 70% RH) and a distance from the source of 60 m (197 ft).

5. For masked, high frequency bands, apply a linear extrapolation from the next lower frequency unmasked band of 0 dB/octave for spectra measured under approach power conditions and -6 dB/octave for spectra measured under full or reduced takeoff power conditions (i.e., takeoff or sideline certification measurement sites). As before, make no correction to masked bands surrounded on each side by unmasked bands.

6. Convert the "normalized" spectra back to the "as measured" distance and weather.

This last step could be changed to allow the "normalized" data (60 m, 25%/70% RH) to be converted back to the proper propagation path length corresponding to a "standard day" flight profile. However, this aspect of data correction procedures was outside the objectives of this program and was not considered. This refinement would also have made it difficult to compare results of all the correction methods on a consistent basis, using "as measured" data with corrections for background noise only.

At this point, some form of quantitative comparison is desirable to provide a more accurate perspective for evaluating the various correction methods described. Such a comparison is presented in the next section.

3.5 Quantitative Comparison of Correction Methods

Before attempting a quantitative comparison of the various correction methods, it was first decided to eliminate from this comparison any temporal extrapolation techniques and to consider only two general types - frequency extrapolation and energy subtraction. As pointed out earlier, while at least one of the temporal extrapolation techniques (see Section 3.3.6) showed great promise, this, or any other temporal extrapolation technique, becomes impossible to apply to a given band which is totally obscured at all times in an aircraft flyover signal. This is not intended to imply that temporal extrapolation should never be used but rather that it cannot always be used and hence is not considered further in this comparative evaluation of candidate correction methods deemed suitable for adoption as FAA-approved standard procedures applicable to all situations.

Another point in favor of preferring frequency extrapolation over temporal extrapolation is that operating on the aircraft noise signal in the frequency domain is more consistent with the use of frequency-dependent aircraft noise metrics such as PNL.

3.5.1 Aircraft Signal and Background Noise Spectra Used for Evaluation

To provide representative spectra for the quantitative comparison of the different correction procedures, the 727 takeoff and approach spectra from Figure 7 were selected. Since the level of the background noise in each band is required for application of the correction procedure, the measured background noise level was increased, first, by 22.7 dB and then by an additional 9.5 dB for the takeoff spectrum and by 15 dB and an additional 4 dB for the approach spectra in order to create hypothetical background noise levels within 5 dB of the "as measured" signal for, first, 4 bands and then 7 bands, respectively. It is recognized that the resulting adjusted background noise levels are unrealistically high; however, essentially the same end result would have been obtained had the aircraft signal been reduced, instead, by comparable amounts. The criterion level of 5 dB was chosen to be representative of the lower end of the critical signal-to-noise ratio span for most of the correction procedures shown earlier in Figure 14.

Proper characterization of the background noise level also required that the frequency range for predetection background noise, additive to the true aircraft signal, be defined. For this example, this frequency range was restricted to the low frequency bands below 200 Hz. At this frequency and above, the background noise was assumed to be postdetection background noise which would mask, without any energy addition, any signal falling below the background noise floor.

Following this background noise definition process, spectra for each of the flyovers were available in the following forms:

1. The noncontaminated true spectra as originally measured.
2. The contaminated spectra. This represents the new "as measured" spectra in which the background noise contributes to the original "as measured" band levels at frequencies below 200 Hz, and at frequencies above 200 Hz, replaces the originally measured level to become the new "as measured" level.
3. The artificially-increasded background noise levels causing the difference between 1. and 2.

These three spectra are tabulated in Tables 3 and 4. The measured bands within 5 dB of the respective hypothetical background noise levels are identified in the tables by an underline.

Figures 15 to 18 show the four situations to be examined for comparison of the different correction procedures. The shaded areas represent the effect of background noise on the true noise signature. Measured aircraft signal bands within 5 dB of the background noise are circled.

To provide a suitable basis for comparing the accuracy of the various correction procedures, both PNL and PNLT values were computed for each of the test spectra after application of each of the correction procedures.

3.5.2 Results

Table 5 compares the results of the different correction procedures on values of PNL and PNLT for the two different 727 spectra. The original "as measured" aircraft spectra represent the reference values for PNL and PNLT which are listed on the first row of Table 5. These values are uncontaminated by

Table 3

Original and New "As Measured" 727 Takeoff Spectra and Corresponding Background Noise Levels to Create 4 and 7 Violations of 5 dB S/N Ratio

Frequency (Hz)	Original as Measured (dB)	4 Violations		7 Violations	
		New (3) Aircraft (dB)	Background(1) Noise (dB)	New (3) Aircraft (dB)	Background(2) Noise (dB)
50	85.7	87.4	82.5	92.9	92.0
63	96.9	97.2	85.5	99.1	95.0
80	96.6	96.8	83.1	98.1	92.6
100	100.6	100.7	82.9	101.2	92.4
125	99.1	99.1	78.1	99.4	87.6
160	98.6	98.6	77.3	98.9	86.8
200	101.7	101.7	76.5	101.7	86.0
250	102.3	102.3	76.5	102.3	86.0
315	101.3	101.3	75.5	101.3	85.0
400	100.5	100.5	76.5	100.5	86.0
500	99.9	99.9	77.2	99.9	86.7
630	99.1	99.1	77.2	99.9	86.7
800	97.3	97.3	76.0	97.3	85.5
1000	97.0	97.0	76.2	97.0	85.7
1250	95.8	95.8	76.0	95.8	85.5
1600	93.9	93.9	75.2	93.9	84.7
2000	92.6	92.6	74.7	92.6	84.2
2500	91.2	91.2	74.5	91.2	84.0
3150	89.5	89.5	74.7	89.5	84.2
4000	86.6	86.6	74.5	86.6	84.0
5000	82.4	82.4	74.0	83.5	83.5
6300	79.2	79.2	74.7	84.2	84.2
8000	74.5	74.5	74.5	84.0	84.0
10000	70.7	75.5	75.5	85.0	85.0

(1) Measured Background Noise increased by 22.7 dB to create 4 "violations."

(2) Measured Background Noise increased by 32.2 dB to create 7 "violations."

(3) Underlined band within 5 dB of New Background Noise Levels.

Table 4

Original and New "As Measured" 727 Approach Spectra and Corresponding Background Noise Levels to Create 4 and 7 Violations of 5 dB S/N Ratio

Frequency (Hz)	Original as Measured (dB)	4 Violations		7 Violations	
		New(3) Aircraft (dB)	Background(1) Noise (dB)	New(3) Aircraft (dB)	Background(2) Noise (dB)
50	72.0	76.6	74.8	79.6	78.8
63	75.3	79.7	77.8	82.7	81.8
80	78.2	80.0	75.4	81.8	79.4
100	79.1	80.5	75.2	82.2	79.2
125	77.9	78.6	70.4	79.5	74.4
160	78.5	79.0	69.6	79.7	73.6
200	79.3	79.3	68.8	79.3	72.8
250	80.5	80.5	68.8	80.5	72.8
315	82.6	82.6	67.8	82.6	71.8
400	80.7	80.7	68.8	80.7	72.8
500	80.0	80.0	69.5	80.0	73.5
630	79.6	79.6	69.5	79.6	73.5
800	76.9	76.9	68.3	76.9	72.3
1000	77.3	77.3	68.5	77.3	72.5
1250	79.1	79.1	68.3	79.1	72.3
1600	76.8	76.8	67.5	76.5	71.5
2000	78.5	78.5	67.0	78.5	71.0
2500	85.0	85.0	66.8	85.0	70.8
3150	83.0	83.0	67.0	83.0	71.0
4000	84.1	84.1	66.8	84.1	70.8
5000	79.6	79.6	66.3	79.6	70.3
6300	79.4	79.4	67.0	79.4	71.0
8000	76.8	76.8	66.8	76.8	70.8
10000	69.6	69.6	67.8	71.8	71.8

(1) Measured Background Noise Level increased by 15.0 dB to create 4 "violations."

(2) Measured Background Noise Level increased by 19.0 dB to create 7 "violations."

(3) Underlined bands within 5 dB of New Background Noise Level.

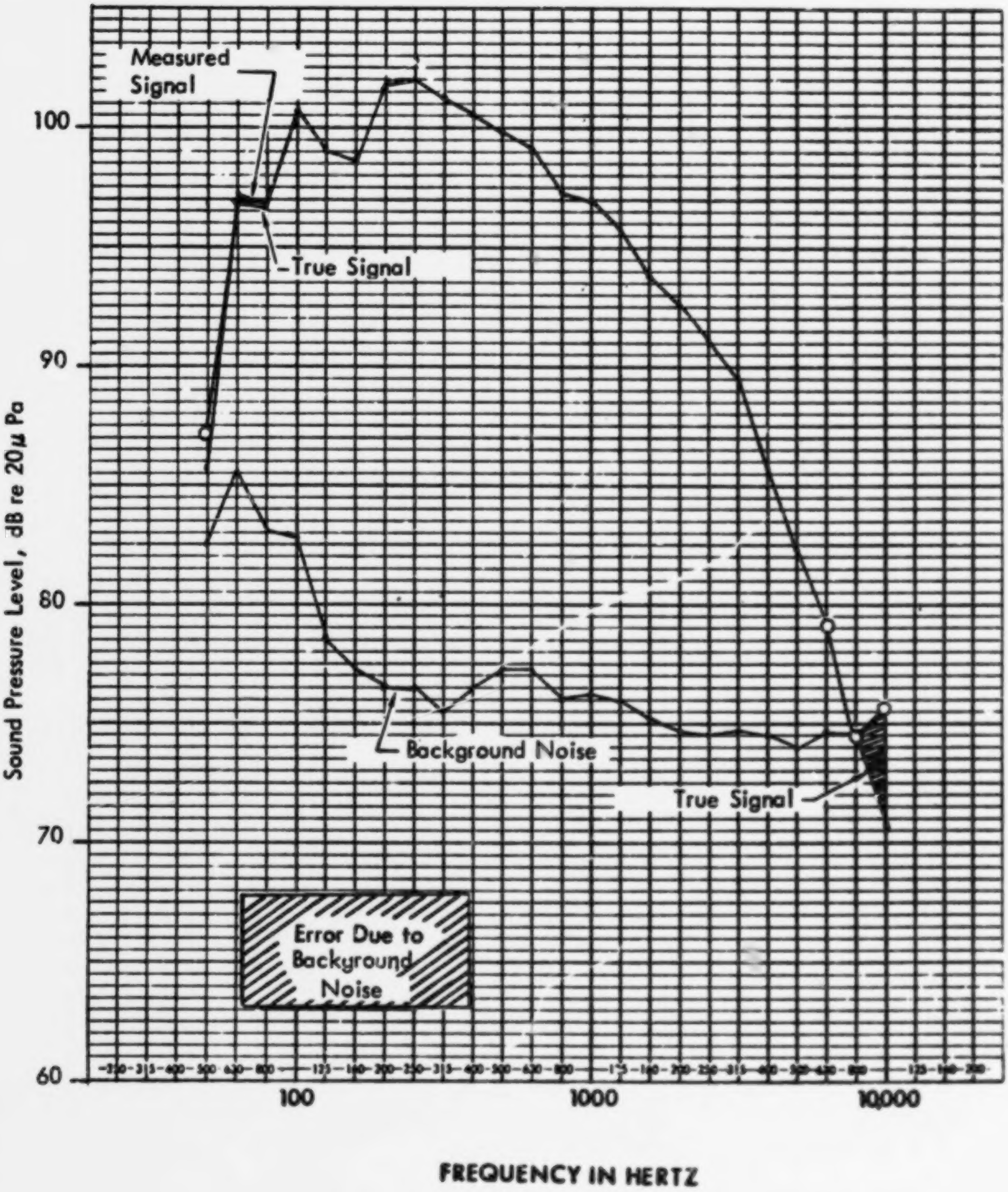


Figure 15. 727 Takeoff with Background Noise Raised to Create Four Bands in Violation of 5 dB Requirement. Bands with o Are Within 5 dB of Background Noise.

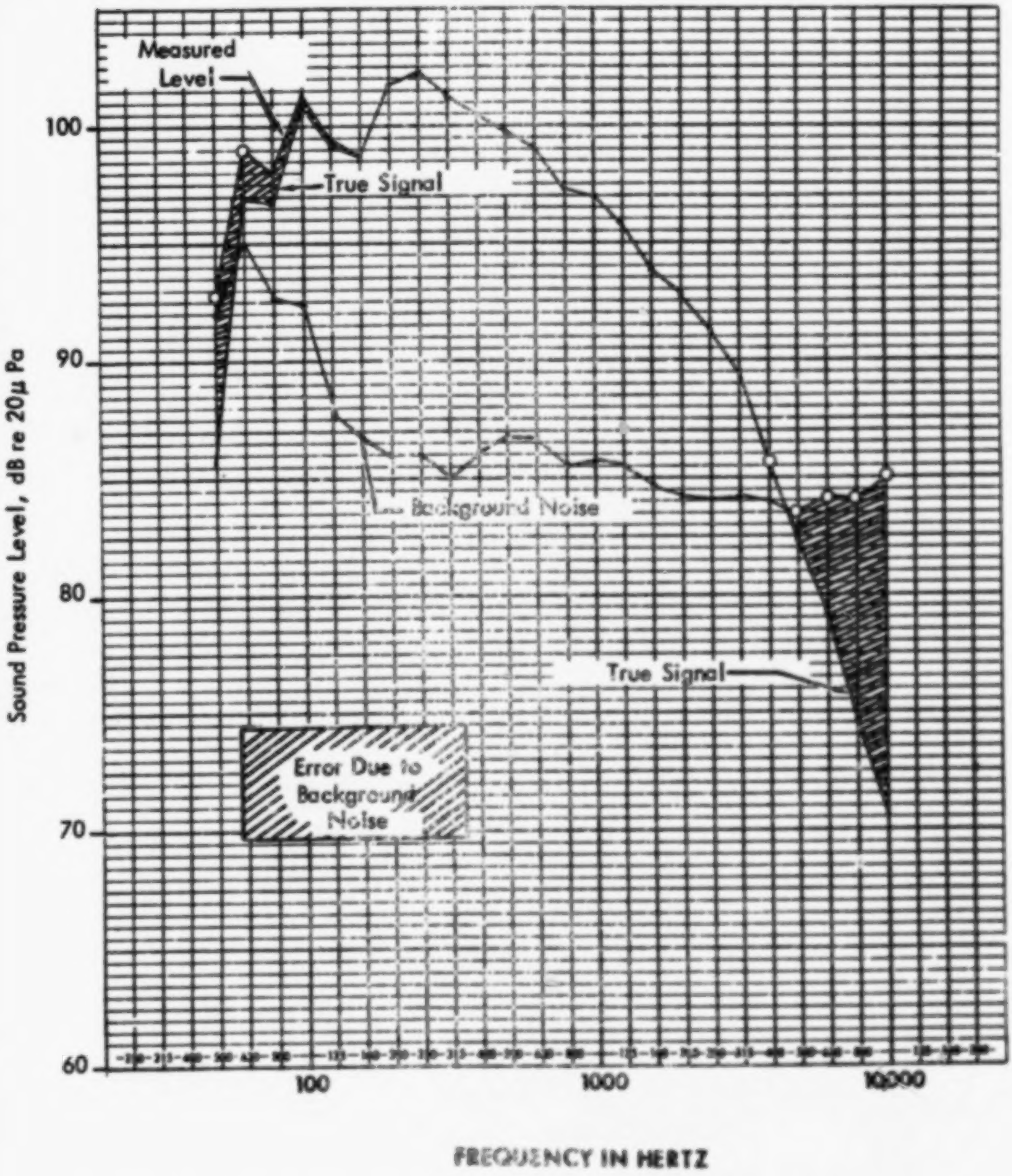


Figure 16. 727 Takeoff with Background Noise Raised to Create Seven Bands in Violation of 5 dB Requirement. Bands with o are Within 5 dB of Background Noise.

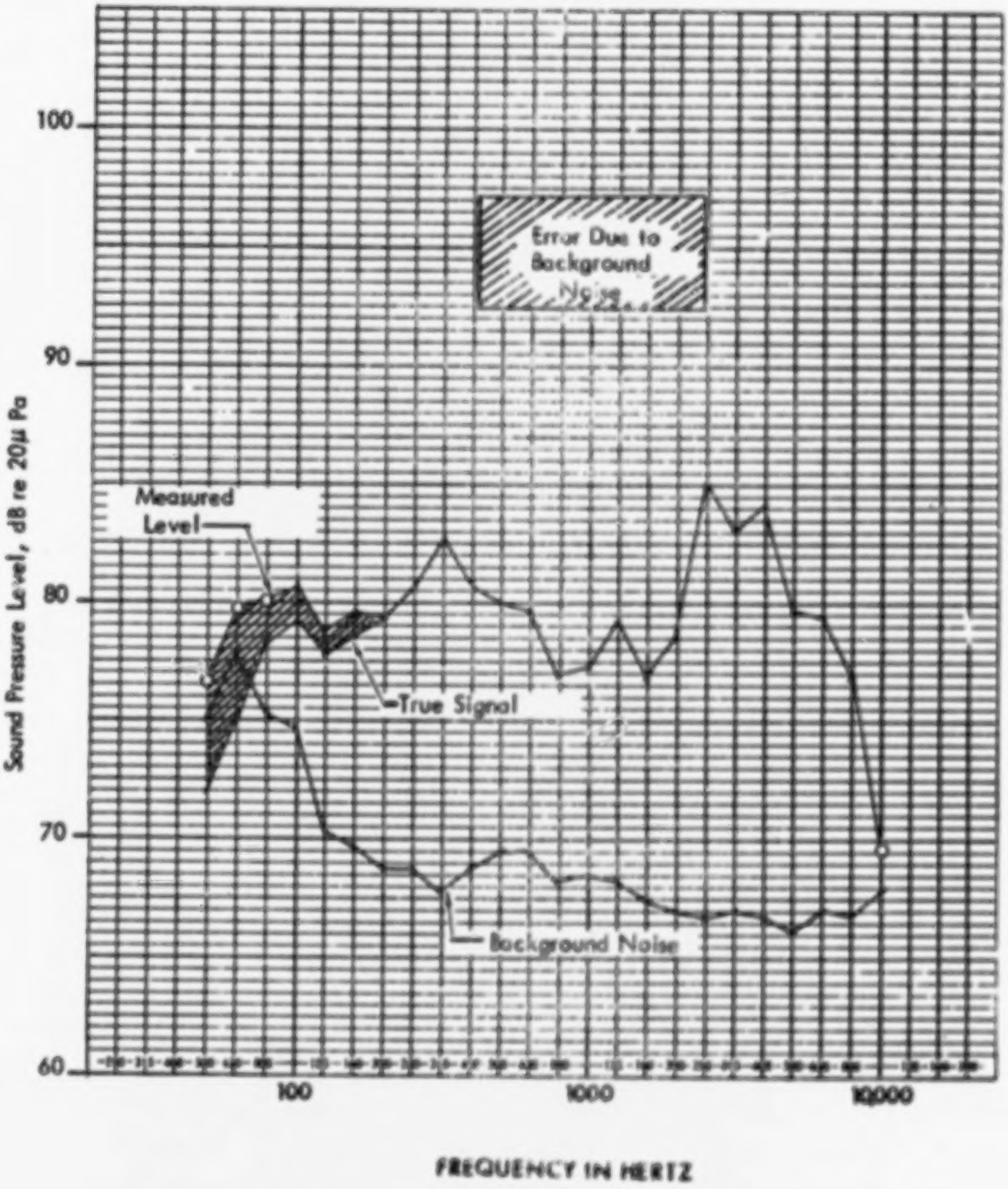


Figure 17. 727 Approach with Background Noise Raised to Create Four Bands in Violation of 5 dB Requirement. Bands with o are Within 5 dB of Background Noise.

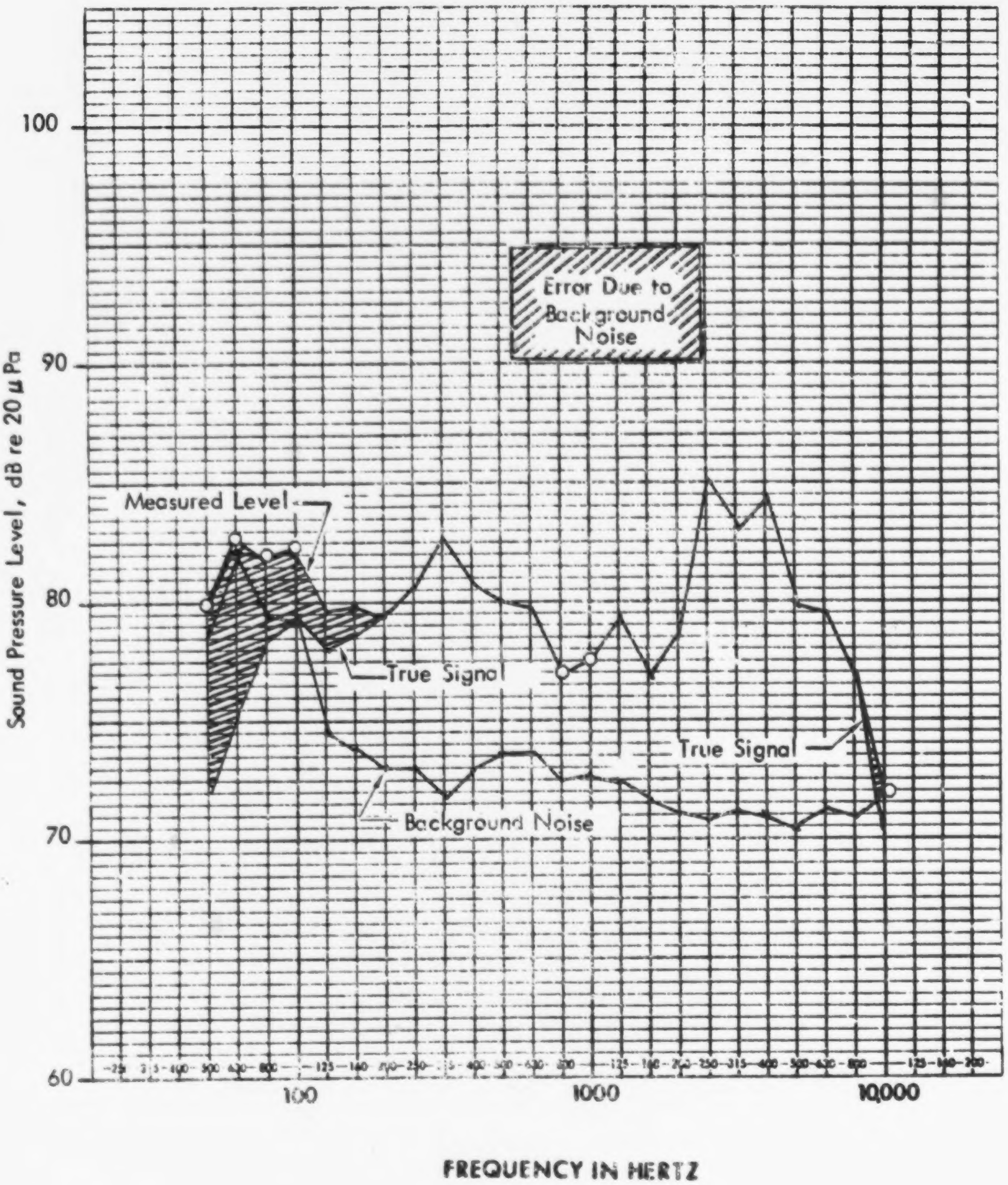


Figure 18. 727 Approach with Background Noise Raised to Create Seven Bands in Violation of 5 dB Requirement. Bands with o are Within 5 dB of Background Noise.

Table 5

Comparison of Results of Applying Various Correction Procedures for Background Noise to Two Representative Aircraft Spectra

Correction Method	727 Takeoff				727 Approach				Avg. Error[d] in PNL or PNLT			
	4 bands ≤ 5 dB		7 bands ≤ 5 dB		4 bands ≤ 5 dB		7 bands ≤ 5 dB		4 bands ≤ 5 dB		7 bands ≤ 5 dB	
	PNL	PNLT	PNL	PNLT	PNL	PNLT	PNL	PNLT	$\overline{X}$	$\pm\sigma$	$\overline{X}$	$\pm\sigma$
True Spectra	118.26	118.72	118.26	118.72	107.00	108.42	107.00	108.42	-	-	-	-
Plus B.N. [a]	+ .06	+ .55	+ .61	+ .42	+ .14	+ .13	+ .31	+ .31	0.22	±0.22	0.41	±0.14
Band Deletion [b]	- .60	- .62	- 1.74	- 1.92	- .43	- .44	- 1.21	- 1.21	0.52	±0.10	1.52	±0.37
FAA (6)	- .12	- .13	- .35	- .26	+ .14	+ .14	+ .28	+ .28	0.13	±0.01	0.29	±0.04
ARP 796[c] (A)	- .32	- .31	- 1.95	- 1.95	- .48	- .44	- 1.18	- 1.32	0.39	±0.09	1.60	±0.41
(B)	- .10	- .09	- .04	- .04	+ .02	+ .06	- .39	- .53	0.07	±0.04	0.25	±0.25
NASA (9, 10) Douglas	- .62	- .63	- 2.08	- 2.11	- .49	- .49	- 1.70	- 1.84	0.56	±0.08	1.93	±0.20
Boeing (12)	+ .14	+ .13	+ .59	+ .41	+ .27	+ .27	+ .18	+ .17	0.20	±0.08	0.34	±0.20
BBN (13)	+ .03	+ .02	- .21	- .19	+ .21	+ .20	+ .27	+ .26	0.12	±0.10	0.23	±0.04
Wyle I	+ .04	+ .03	+ .12	+ .12	+ .06	+ .06	+ .06	+ .06	0.05	±0.02	0.09	±0.03
Wyle II	- .03	- .03	+ .14	+ .13	+ .03	+ .03	+ .03	+ .03	0.03	±0.00	0.08	±0.06

[a] True Spectra contaminated with background noise adjusted to level necessary to cause specified number of violations (i.e., 4 or 7 bands within 5 dB of background noise)

[b] Violating bands deleted

[c] Method A of Proposed SAE ARP 796[11] excluded violating bands; Method B uses extrapolation based on nearest three nonviolating bands.

[d] Absolute Value in dB

the original "as measured" background noise since the latter was at least 20 dB below the original aircraft spectra. The remaining values in the table represent the difference between the new aircraft noise levels and the reference PNL or PNLT values in the first row for each of the new noise-contaminated spectra (see second row) and after application of the correction procedures considered (rows 3 to 11). The correction methods reported in References 7 and 8 were not included since the results after applying these methods were expected to be very similar to results with methods of References 11 and 6, respectively. At the right side of the table are the average and standard deviation of the absolute difference in PNL or PNLT values for each correction method and for each background noise level (i.e., 4 and 7 bands less than 5 dB above the background noise, respectively).

As shown in the second row, the noise contaminated spectra, without any correction at all, have an average error of 0.22 and 0.41 dB for the two levels of background noise. Several of the "corrected" spectra show an even greater error. Clearly, for the particular test spectra evaluated, these correction methods are worse than no correction at all. Considering only the first level of background noise which causes no more than 4 "as measured" signal bands to fall within 5 dB of the background noise (i.e., the current limit in the Regulation), three of the correction methods evaluated show an average residual error in the corrected PNL or PNLT values of less than 0.1 dB. These are version B of the SAE ARP 876 proposal[11] and both Wyle methods. At the higher level of background noise where 7 bands violate the 5 dB criteria, only the two Wyle methods still show an average residual error less than 0.1 dB. However, three other methods, those from References 6, 11, and 13, show an average error of less than 0.3 dB.

The correction methods which involve deleting bands within 5 dB of the background noise consistently show the largest error and, as suggested earlier, will not be considered for recommendation as "FAA approved" methods. Since the two Wyle methods show very little difference in average error, the simpler version, Wyle I, would appear to be a very suitable candidate for a simple and accurate correction method for background noise. This was essentially the method employed for correcting the remaining data acquired for this program (see Appendix A) for application to other aspects of this overall study of correction procedures for aircraft noise data.[15] (The only difference is that the slope for extrapolating to replace high frequency masked bands was a constant -9 dB/octave instead of the optionally higher slope provided for in the description of Wyle Method I, Step 4.)

The results of this analysis also shed light on the questions posed earlier at the beginning of Section 3.2.

- Concerning the need for any background noise correction, the results in the second row of Table 5 show that errors in PNLT of the order of +0.1 to 0.6 dB resulted when up to 4 bands violated the 5 dB criteria and no corrections were applied to reduce this error. Unless this is an acceptable error, background noise corrections must be applied.
- If no more than 4 bands in any one-half second spectra exceeded the 5 dB criteria, then, since this would usually occur for only a portion of the one-half second PNLT values out of all those involved within the 10 dB down period, the error in EPNL would normally be less than the PNLT errors just defined. However, in some cases where several bands were missing throughout the entire time history, EPNL errors comparable to the 0.1 to 0.6 dB range could occur. Thus, it is recommended that background noise corrections be applied to all one-half second spectra within the 10 dB down period and not to just the PNLTM spectra.
- There is no solid basis for allowing a mixed criteria of not-correcting one-half second spectra with less than 4 violating bands and requiring corrections for other spectra. However, it is felt that this complication in a correction procedure would be both undesirable, from the standpoint of accuracy, and impractical, from the standpoint of simple implementation procedures.
- The correction procedures that appear most favorable, version B of the SAE ARP 876 proposal and Wyle Method I, are best implemented at the beginning of signal processing before the 10 dB down duration is exactly defined. However, if desired, initial conservative estimates of this time period can be made in order to limit the number of

one-half second spectra to which background noise corrections are applied.

3.5.3 Maximum Allowable Background Noise Level

One final point needs to be made concerning the background noise correction procedure currently specified in Appendix A of the Regulation. As stated in the introduction, Paragraph A36.3(f)(3) includes the separate requirement for background noise that its PNL must be at least 20 PNdB below the maximum PNL of the aircraft. Based on the accuracy of the best background noise correction methods, it seems reasonable to consider allowing this 20 PNdB differential to be reduced to about 15 dB, providing all one-half second spectra within the "10 dB down" period were corrected, at all frequencies, for background noise using the optimum methods defined above.

As a matter of practical interest, the PNL of typical background noise levels that actually occur during aircraft noise measurements are usually much more than 15 dB below the maximum PNL of the aircraft flyover noise. For the first 50 of the aircraft flyby measurements obtained at LAX for this study, which are defined in Appendix A, the average difference between the background PNL and PNL of the aircraft, at PNLTM, was 25 dB with a standard deviation of 6.5 dB. Only 4 percent of the measurements had PNL aircraft signal-to-background noise ratios less than 15 dB and the accuracy of the EPNL values for these is probably marginal. However, another 24 percent had a PNL signal-to-background noise ratio between 15 and 20 dB and valid EPNL values were obtained from these measurements.

4.0 BACKGROUND NOISE CORRECTION METHODS - LIGHT PROPELLER AIRCRAFT

As defined in Appendix F of the Regulation, the current background noise correction procedure for noise certification of light propeller aircraft is limited to one simple requirement. The measured maximum A-weighted aircraft noise level must exceed the A-weighted background noise level by at least 10 dB or an approved method must be applied to the measured data to correct for the contribution of this noise. No specific procedures were found in the literature which constituted candidate "FAA approved" methods. Therefore, the following simple analytical approach and supporting field measurement procedure was developed to provide the possible basis for such an approved method.

It will be shown that the "as measured" A-weighted aircraft noise level, when measured directly on a sound level meter with the A-weighting network employed, can be corrected for the contribution of background noise by simply subtracting, on an energy basis, the corresponding A-weighted level of the latter. This process does not involve breaking the aircraft and background noise signals down into one-third octave bands, although such an analysis may be desirable, in some cases, to allow corrections to the data for nonstandard weather conditions. It also does not involve consideration of the two types of background noise. Only predetection, energy-adding background noise is involved. It will always be necessary to have a measurable signal above the postdetection noise floor of the sound level meter in order to make any valid observation.

4.1 Analytical Basis for Correction Method

It is convenient, at this point, to assume that the aircraft and noise signal have, in fact, been analyzed into one-third octave band spectra. To simplify the notation, let A_i and N_i represent, respectively, the relative intensity of the aircraft and background noise signals in the i-th one-third octave band. Similarly, let W_i represent the relative weighting, in terms of intensity, for an A-weighting network. These three quantities can then be defined by:

$$A_i = 10^{L_A(f_i)/10}$$

$$N_i = 10^{L_N(f_i)/10}$$

and $$W_i = 10^{W(f_i)/10}$$

where $L_A(f_i)$ and $L_N(f_i)$ are the one-third octave band levels, in dB, of the aircraft and background noise signals, respectively, for the i-th band and $W(f_i)$ is the A-weighting factor, in dB, for the same band.

The "as measured" A-weighted aircraft noise level, L_{TA}, including the energy addition of the background noise, can be expressed by the summation over all 24 one-third octave bands, of the combined, A-weighted intensity of the aircraft and background noise signals as:

$$L_{TA} = 10 \log \left[\sum_{i}^{24} (A_i + N_i) \cdot W_i \right] \quad , \text{dB} \tag{4}$$

Similarly, the A-weighted background noise level alone, L_{NA}, neglecting, for now, its statistical fluctuation, will be:

$$L_{NA} = 10 \log \left[\sum_{i}^{24} (N_i \cdot W_i) \right] \quad , \text{dB} \tag{5}$$

The "as measured" aircraft signal, including background noise, could now be corrected for the contribution of the latter by subtracting it, on an energy basis, one band at a time and then re-adding the noise-corrected band levels to determine the true A-weighted level (L_A) of the background-noise-free aircraft signal. This operation can be represented by

$$L_A = 10 \log \left[\sum_{i}^{24} \left[(A_i + N_i) - N_i \right] \cdot W_i \right] \tag{6}$$

$$= 10 \log \left[\sum_{i}^{24} A_i \cdot W_i \right] \quad , \text{db} \tag{7}$$

However, the summation in Eq. (6) can also be expressed as:

$$L_A = 10 \log \left[\sum_{i}^{24} (A_i + N_i) \cdot W_i \; - \; \sum_{i}^{24} (N_i \cdot W_i) \right]$$

$$= 10 \log \left[10^{L_{TA}/10} - 10^{L_{NA}/10} \right] \qquad (8)$$

and one obtains an expression which simply describes the process of subtracting, on an energy basis, the overall A-weighted background noise level from the "as measured" A-weighted aircraft-noise level. Thus, the desired noise-free A-weighted [illegible] signal level can be obtained very simply without having to revert to one-third octave band analysis.

Statistical Considerations

The preceding analysis necessarily assumed that the measured background noise level accurately represented the level existing at the time the combined aircraft and background noise level was measured during an overflight. Appendix B analyzes the statistical error involved in this assumption.

First of all, it is assumed that the background noise can be treated as a stationary random signal with a normal distribution of noise levels. Then, a 50 percent safety factor is applied to allow for deviation from this ideal model. The result is a simple rule of thumb for the "as measured" signal-to-noise ratio which has been selected so that one could expect less than a 1 percent chance that the average of the "as measured" aircraft noise levels, after correction on an energy basis, for the background noise, will be understated by a residual error greater than 0.1 dB. By the same rule, one should also expect that there is less than a 0.1 percent chance that the residual error exceeds 0.5 dB. This rule of thumb for the recommended "as measured" signal-to-noise ratio, S/N, for measurement of A-weighted noise levels of light aircraft is

$$S/N \simeq 5 + \sigma \quad , \text{db} \qquad (9)$$

where σ is the standard deviation of the background noise level in dB. A simple field procedure for estimating the latter is defined in the next section.

The residual error, considered here, assumes that the corrected aircraft noise level is based on the results of at least six separate flights, as required by Appendix F of the Regulation, and that the aircraft signal from each flight is corrected, on an energy basis, for background noise level. (This small residual error is attributable only to the randomness of the background noise and would usually be exceeded by other errors due to the measurement system or off-reference flight conditions.)

Following the concepts just described and assuming a typical standard deviation for the acoustic ambient background noise of 5 dB, a recommended "as measured" signal-to-noise ratio of 10 dB is obtained. This is consistent with the current requirement in Appendix F of the Regulation. Therefore, no change in this criteria is recommended at this time, although a higher signal-to-noise ratio would be desirable in situations where σ was much greater than 4 dB and highest accuracy is desired for application of the background noise correction.

A lower signal-to-noise ratio than the recommended minimum value defined by Eq. (9) can be used at the expense of an increase in the statistical error due to the randomness of the background noise. For example, based again on the average of six tests and the same 50 percent safety factors as employed earlier, the following alternative expressions could be used to define less conservative "as measured" signal-to-noise ratios. For less than a 1 percent chance of exceeding a residual error of underestimation of 0.5 dB, the required signal-to-noise ratio should be

$$S/N \simeq 1 + 0.5\sigma \quad , \text{dB} \tag{9a}$$

and for less than a 1 percent chance of exceeding a residual error of underestimation of 1.0 dB, the required signal-to-noise ratio should be

$$S/N \simeq 0.5 + 0.3\sigma \quad , \text{dB} \tag{9b}$$

Thus, for an average σ of 5 dB, these expressions indicate required signal-to-noise ratios of 3.5 and 2 dB, respectively.

In lieu of accepting these lower signal-to-noise ratios and corresponding increases in statistical errors, the preferred approach would be to employ a lower flyover altitude for data acquisition to achieve the desired signal-to-noise ratio given by Eq. (9) and then correct the measured level back to the standard 1000 ft flyover altitude.

4.2 Field Measurement Procedure

In Section B-6 of Appendix B, the subject of statistical error associated with measurement of the background noise is discussed in detail. The following steps summarize the basic procedure developed.

1. Using a standard sound level meter set to A-weighting and "SLOW" response, read a total of 20 preliminary "snapshot" samples of the instantaneous background noise level every 15 seconds over a total period of 5 minutes (15 second intervals provide a comfortable spacing to allow one observer to record the data between readings).
2. Compute the standard deviation (σ) of this sample of 20 readings (see Section B.6.1 in Appendix B for the relevant expression).
3. If this initial estimate of the standard deviation of the background noise is 4 dB or less, accept the arithmetic mean value of this sample of 20 readings as the true mean A-weighted background noise level to be subtracted, on an energy basis, from each of the "as measured" aircraft noise levels.
4. If the initial estimate of the standard deviation (σ) exceeds 4 dB, compute the size, N, for a larger sample by

$$N = 20\left[\sigma/4\right]^2 \tag{10}$$

5. Repeat the "snapshot" measurement procedure of Step 1 but, for the new, larger sample retaining, for convenience, the same sampling interval of 15 seconds. Use the mean value from this larger sample for application of the energy correction for background noise.

For example, if the initial estimate of the standard deviation of the background noise was 6 dB, then a new sample should be made for a total of $20(6/4)^2 = 45$ samples every 15 seconds over a period of $45 \times 15 = 675$ seconds, or about 11 minutes.

If all measurements are tape recorded instead of being read directly on a sound level meter, then each "sample" can be considered as lasting 1 second and, in the above example, a 45 second continuous recording of the background noise would be required, instead of an intitial 20 second recording, in order to establish the final mean background noise level.

5.0 RECOMMENDATIONS FOR BACKGROUND NOISE CORRECTIONS TO NOISE CERTIFICATION MEASUREMENTS FOR AIRCRAFT

The results presented in the preceding sections have been used to develop the following recommendations for consideration by FAA. These recommendations are designed to provide a framework for "FAA approved" methods to correct aircraft noise certification measurements for the influence of background noise. There is also a need to establish similar correction procedures in ICAO Annex 16. However, it is expected that the following recommendations should undergo a careful review by FAA and by various segments of the aviation industry before they should be considered by ICAO or be adopted by FAA as "approved methods."

5.1 Correction Procedure for Jet and Large Propeller Aircraft

1. The correction procedure should be based on explicit recognition of two types of background noise - the energy additive type which is introduced into the measurement system before the signal detector and the non-additive masking type which is present as a noise floor in the analyzer output. These two types can be conveniently labeled predetection and postdetection background noise. Corrections for these two types of background noise should be applied, as appropriate, to all bands, for each one-half second spectra throughout the 10 dB down period and not to just the spectra at PNLTM. (Simple procedures, such as defined in Section 2.2, should be used to identify the frequency range dominated by each type of background noise.) Furthermore, it is recommended that (1) for consistency, an FAA-approved background noise correction procedure be applied at all times, regardless of the level of the background noise, and (2) consideration be given to allowing the PNdB differential between the background noise and the maximum PNL of the "as measured" aircraft signal to be reduced from 20 to 15 PNdB, providing the rest of the recommended correction procedures are employed.

2. In the frequency range where the former energy-adding type of noise is present, a simple energy subtraction of the background noise should

be applied to each one-third octave band whose level is at least 0.46 dB above the background noise. For bands below this criterion level, a maximum correction of -10 dB is applied.

3. In the frequency range where the latter (masking) type of background noise is present, whenever the "as measured" one-third octave band level is at least 2 dB above this background noise floor, or is surrounded by bands which satisfy this criterion, no correction is applied.

4. Whenever one or more of the contiguous high frequency "as measured" one-third octave band levels is less than 2 dB above this background noise floor, they shall be considered as masked bands and replaced by extrapolated values starting from the (unmasked) one-third octave band with the highest frequency which is also 2 dB or more above the background noise floor. The extrapolation slope shall be -9 dB/octave or, if greater, the slope corresponding to the difference between the highest frequency unmasked band and the (masking) background noise floor.

5. The one-third octave band levels of the background noise should be based on a sample of at least 20 second duration, or longer if the estimated standard deviation of the background noise exceeds 4 dB. A specific procedure for defining a suitable measurement period is given in Section B.6 of Appendix B.

6. The current default provision in the Regulation allowing deletion of up to 4 one-third octave bands in any one-half second spectrum is considered a questionable procedure to retain in the Regulation. It showed a consistent tendency to underestimate the true PNLT by about 0.5 dB for the cases considered in this study. However, a more detailed evaluation of this procedure may be necessary before it can be categorically rejected as unsuitable for a default background noise correction procedure.

5.2 Correction Procedure for Light Propeller Aircraft

1. The recommended procedure simply involves applying energy subtraction of the A-weighted background noise level to the A-weighted "as measured" aircraft noise level for each of the six or more tests required by Appendix F of the Regulation.

2. The A-weighted background noise level should be measured from a sample of at least 20 "snapshot" readings with a standard sound level meter. If the background noise is determined from a continuous tape recording, a 20 second recording is the equivalent minimum sample period. More samples (or corresponding longer recording times) are recommended if the standard deviation of the estimated background noise level exceeds 4 dB (see Section B.6 of Appendix B for specific details).

3. The current requirement in Appendix F for a nominal signal-to-noise ratio of 10 dB should be retained as a minimum criterion for measurements of light propeller aircraft. In some cases, this will be difficult to achieve at the currently required overflight altitude of 1000 ft. In this case, it may be necessary to either accept a greater statistical error at a lower signal-to-noise ratio or, preferably, use lower altitudes for the measurements and apply suitable corrections for the change in propagation distance.

REFERENCES

1. U.S. Department of Transportation, Federal Aviation Administration, Federal Aviation Regulations, Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification," Change 12 effective 15 January 1979.

2. American National Standards Institute, "American Acoustics Terminology," ANSI S1.1-1960 (R 1976).

3. Bonvallet, G. L., "Levels and Spectra of Traffic, Industrial, and Residential Area Noise," J. Acoust. Soc. Am. 23, 435-439, 1951.

4. Veneklasen, P. S., et al. "Noise Exposure and Control for the City of Inglewood," Paul S. Veneklasen and Associates, November 1968.

5. Donley, R., "Community Noise Regulations," Sound & Vib., 12-21, February 1969.

6. McCollough, J. B. and True, H. C., "Effect of Temperature and Humidity on Aircraft Noise Propagation," Report No. FAA-RD-75-100, U. S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D. C. 1975.

7. Griffiths, D., "Certification Correction Procedures," Federal Aviation Administration, (Draft), August 1978.

8. Rickley, E., personal communication, U. S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, July 1978.

9. Hosier, R. N., "A Comparison of Two Independent Measurements and Analyses of Jet Aircraft Flyover Noise," NASA-TN-D-8379, National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, June 1977.

10. DeLapp, R. E., "Aircraft Noise Definition, Phase II," prepared for U. S. Department of Transportation, McDonnell Douglas Aircraft Company, Long Beach, California, August 1974.

11. Society of Automotive Engineers, Proposed Revision of ARP 796 - "Measurements of Aircraft Flyover Noise," revised 29 January 1976.

12. Hiatt, D. L., et al., "727 Noise Retrofit Feasibility, Vol. III - Upper Goal Flight Testing Summary," Report No. FAA-RD-72-40, Boeing Commercial Airplane Co., Seattle, Washington, June 1973.

13. Bishop, D. E. and Galloway, W. J. "Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data," Wright-Patterson Air Force Base Report No. AMRL-TR-73-107, Bolt Beranek & Newman, Inc., Canoga Park, California, August 1975.

14. Society of Automotive Engineers, A-21 Aircraft Noise Measurement Committee, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity," ARP 866A, March 1975.

15. Rackl, R., "Correction Procedures for Aircraft Noise Data, Volume I: Pseudotones," FAA Report No. FAA-EE-80-1, Vol. I, December 1979.

APPENDIX A

AIRCRAFT NOISE DATA ACQUISITION AND PROCESSING

A.1 Acquisition

Measurement sites in the vicinity of Los Angeles International Airport (LAX) were used to obtain samples of measured noise for different types of aircraft at locations representative of FAR Part 36 (takeoff, sideline and approach). The locations are shown in Figure A-1 and described in Table A-1. The takeoff location is much closer to brake release than specified in the Regulation because of airport geography restrictions.

Microphones were placed at ground level, 1.2 m and 10.0 m as shown in Figure A-2 over both a hard surface (concrete/asphalt) and a soft surface (sand/grass) with the two surfaces separated by about 10 m. In all cases, the microphones were oriented with the diaphragm horizontal. The ground level microphone was located with its diaphragm a distance of 1.27 cm (0.5 in.) above the ground surface. Measurement sites were selected to be in open, generally flat areas as free as possible of nearby reflecting obstacles.

Three two-channel Nagra tape recorders were used to record the acoustic pressure signals from the six microphones. Correlation between microphones was maintained by using a common IRIG-B time code generator as shown in Figure A-3. The IRIG time was noted at aircraft overhead (or sideline) together with airline/flight number/ aircraft type information. A photograph was taken at the aircraft overhead position (or point of closest approach for sideline). The microphones were B&K half inch condenser type 4133. Windscreens were used on each microphone. Calibrations were performed on each tape immediately before the start of measurement using pistonphones (B&K types 4220 and 4230) and a pink noise generator (General Radio 1382). The same three calibrations were recorded at the end of each tape. Recordings of the acoustic and electric background noise level were also made at several times during the test series.

The tapes were reviewed in the laboratory by examining the L_A time history (see Figure A-4), and selections made for digitizing. Aircraft powered by different

A-2

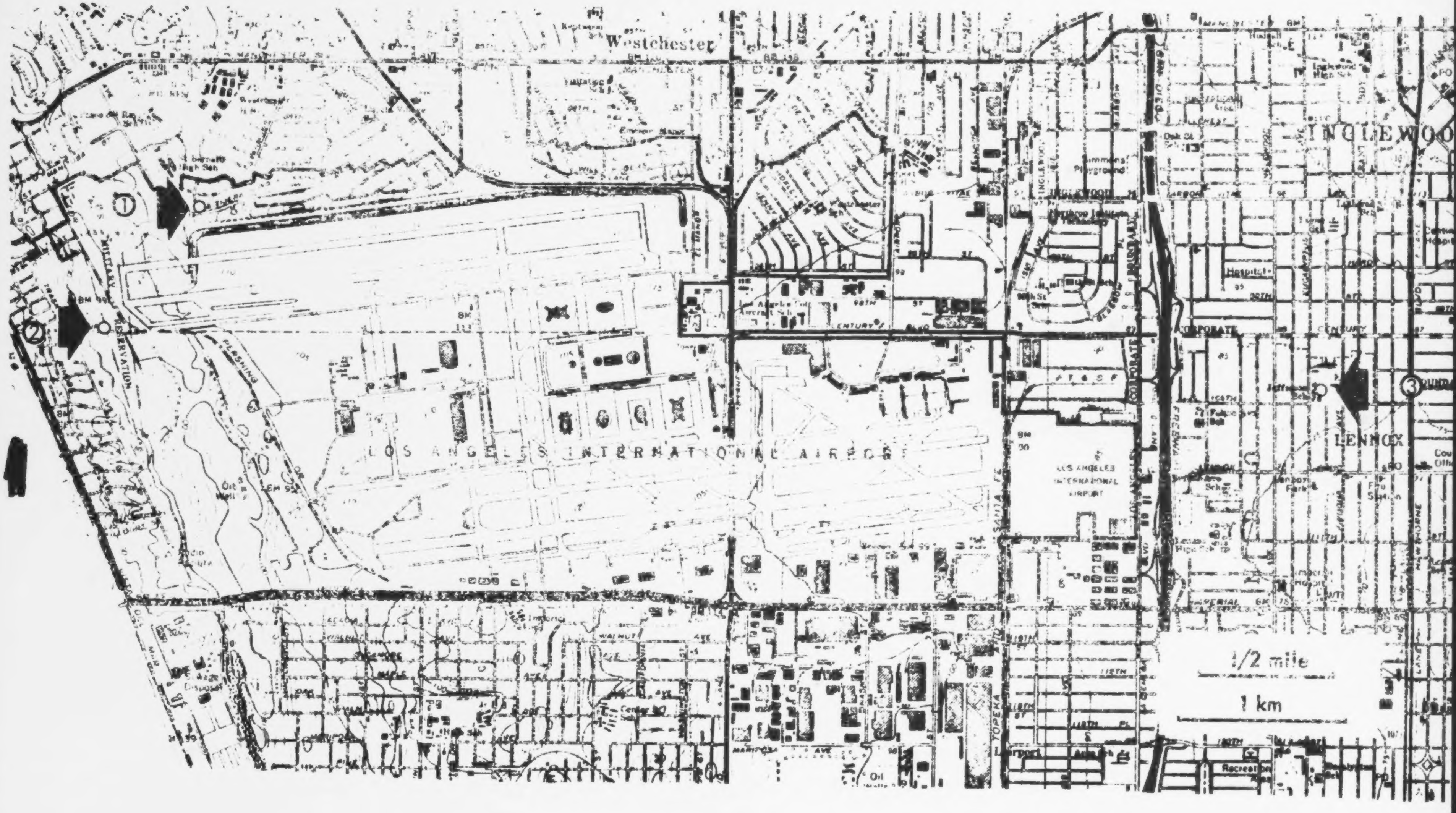

Westchester
INGLEWOO
LENNOX
LOS ANGELES INTERNATIONAL AIRPORT
LOS ANGELES INTERNATIONAL AIRPORT
CENTURY
CORPORATE
MANCHESTER
①
②
③
1/2 mile
1 km

Figure A-1. Location of Measurement Sites Around Los Angeles International Airport

Table A-1

Microphone Locations and Surface Conditions

1. Sideline Location (9000 Feet from Brake Release, 1600 Feet Sideline)

   Microphone Altitude/Surface:

   10 Meters/Sandy Grassland
   10 Meters/Asphalt
   1.2 Meters/Sandy Grassland
   1.2 Meters/Asphalt
   *Ground/4' x 4' x 3/4" Plywood Board over Grass
   *Ground/Asphalt

2. Takeoff Location (11,100 Feet from Brake Release, 200 Feet Sideline)

   10 10 Meters/Concrete
   1.2 Meters/Concrete
   *Ground/Concrete

3. Approach Location (7000 Feet from Threshold, Under Flight Path)

   10 Meters/Grass (Short Cut)
   10 Meters/Asphalt
   1.2 Meters/Grass (Short Cut)
   1.2 Meters/Asphalt
   *Ground/4' x 4' x 3/4" Plywood Board over Grass
   *Ground/Asphalt

*Ground microphones were inverted with 1/2 inch space between diaphragm and ground surface or wooden board.

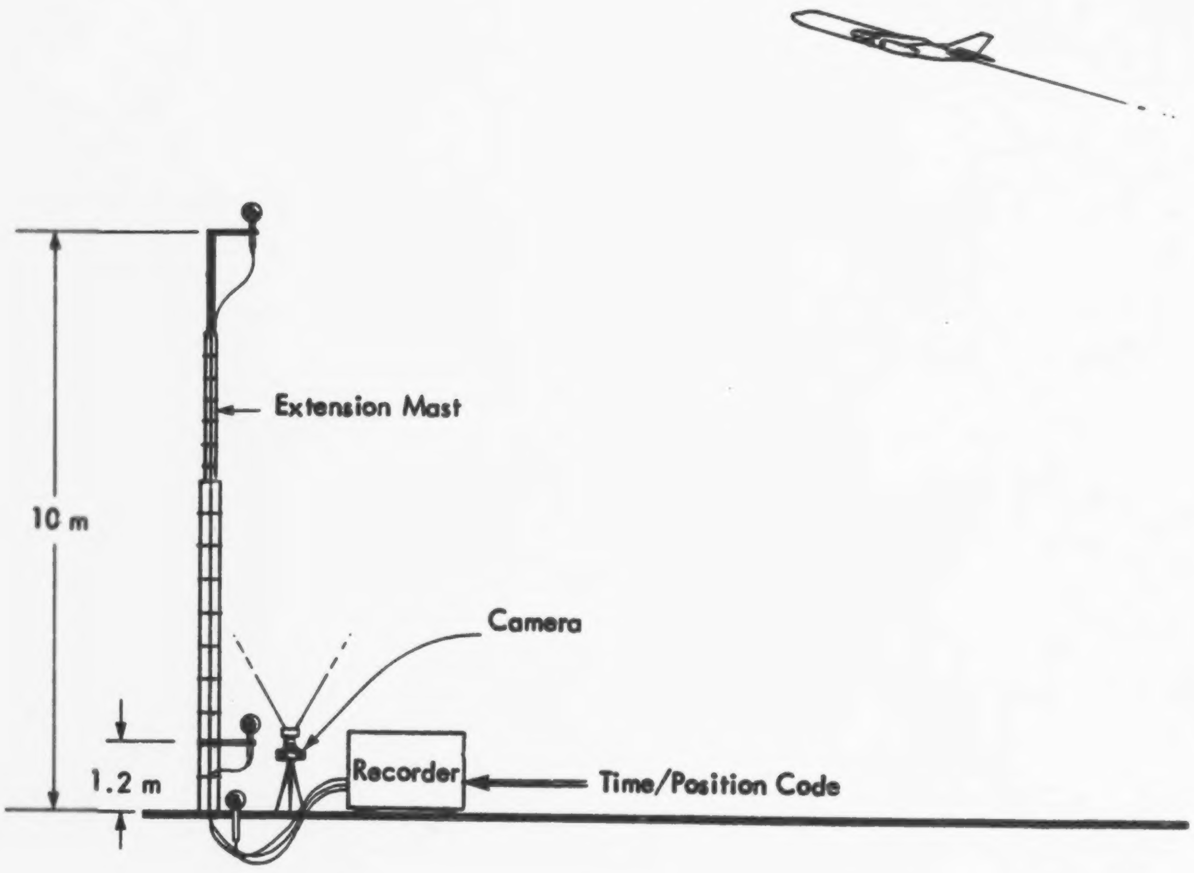


Figure A-2. Three Microphone Array (10 m, 1.2 m and Ground Microphone for Measurement of Aircraft Flyover Noise (Hard and Soft Ground Surface).
Note: Ground microphone was inverted, not embedded into ground as shown.

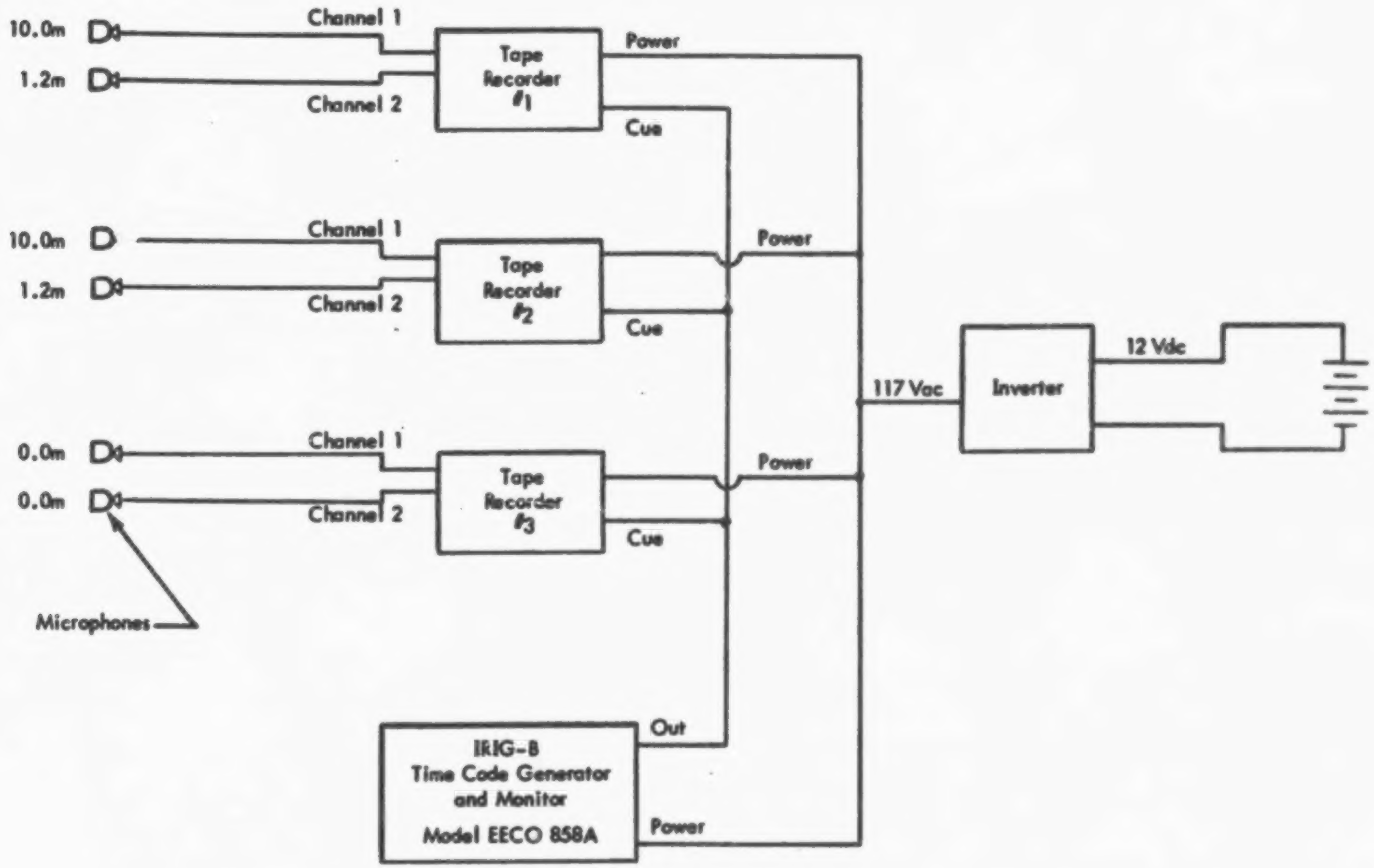


Figure A-3. Instrumentation Block Diagram

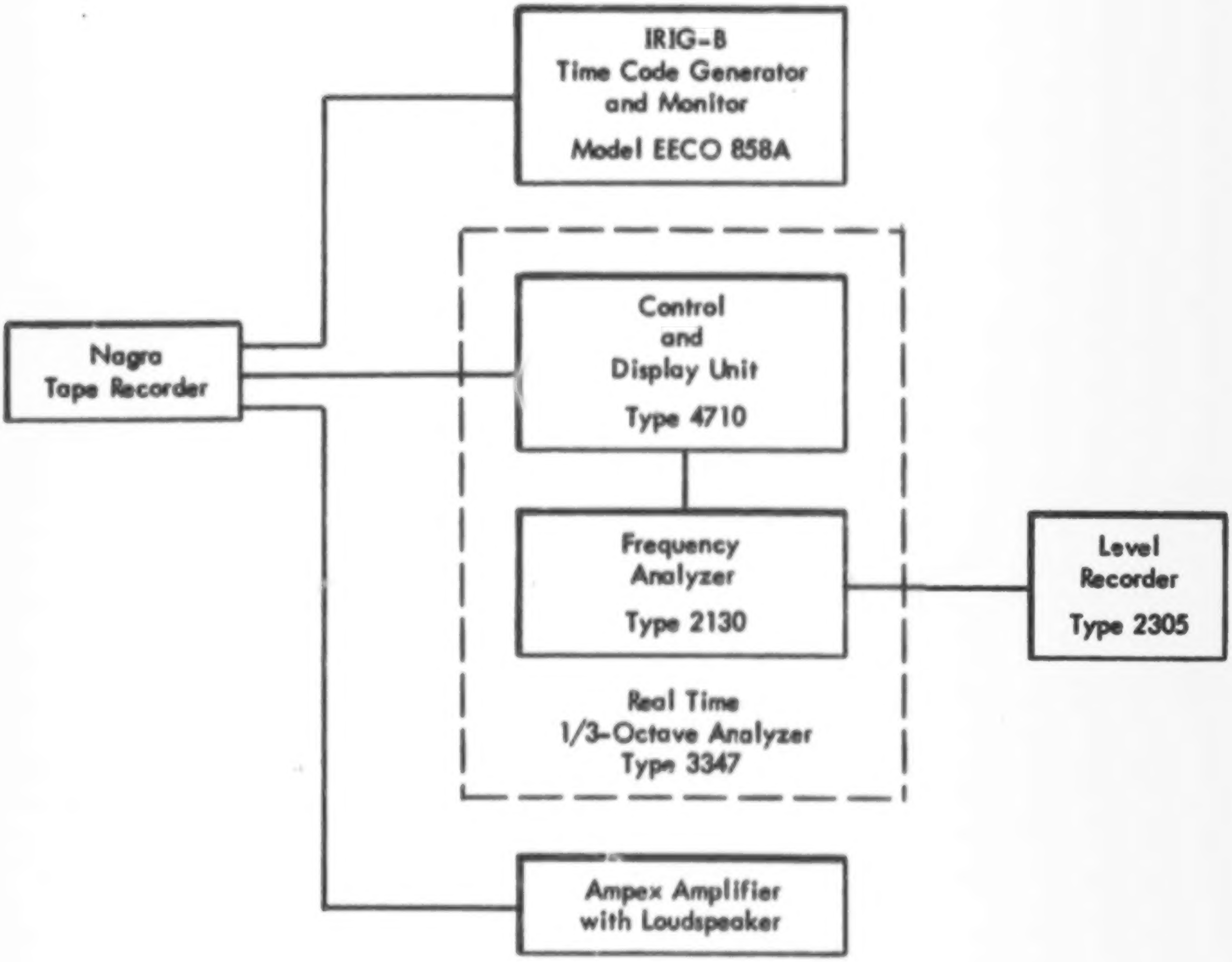


Figure A-4. Flow Diagram of a Preliminary Data Reduction power plants (high by-pass and low by-pass engines) were selected for each of the locations.

Digitization of the selected flyovers and of the background noise was performed with the use of a GR 1926 multichannel rms detector and a GR 1925 one-third octave band filter system. The average sound pressure level for each one-half second of each selected flyover for each of the 24 frequency bands was obtained and stored without consideration of time constant requirements, i.e., no temporal weighted averaging was incorporated in the digitization process. A PDP 11 computer was used to write the digitized data on tape and, after reformatting, the data was stored by Wyle Laboratories on a Univac 1108 computer for analysis (one-third octave band sound pressure level data one-half second time histories referred to as "spectral time histories" or STH).

In order to capture where the aircraft was located relative to the microphone at the time of noise emission corresponding to each one-half second of recorded data, data from the FAA ARTS (Area Radar Tracking System) were provided (by courtesy of FAA). The aircraft overhead time was used to correlate ARTS time and the IRIG-B time code. The ARTS data was used to determine aircraft speed and flight path gradient as well as distance to the microphone.

Meteorological data was recorded before and after each period of noise measurement.

Spectral time history plots for selected flyovers are contained in Appendix A of Volume I of this series of reports.[15]

Prior to utilization of the data for this study on background noise, the data were "cleaned" by applying the following temporal smoothing process.

A.2 Data Processing

The instantaneous one-half second spectra were smoothed in the time domain according to FAR Part 36, Section A36.3(d)(5). The formula used in this study was:

$$SPL_{smoothed,\, i} = 10 \log_{10} \left(0.2\, z^{SPL_{i-2}} + 0.35\, z^{SPL_{i-1}} + 0.45\, z^{SPL_{i}}\right) \text{, dB}$$

where SPL is the sound pressure level in dB in any one one-third octave band, i indicates the current one-half second sample (i - 1 identifies the sample one-half second earlier, i - 2 identifies the sample observed 1 second before "i"), and z equals $10^{0.1}$.

The preceding temporal weighting expression was provided by Mr. Ed Rickley of the DOT Transportation Systems Center. It is based on a trial and error evaluation of suitable weighting constants for the sum of three successive one-half samples which gives approximately the same level for a variety of short pure-tone pulses (e.g. 1/2 sec long) applied to either a computerized aircraft noise data reduction system or a standard sound level meter. The result is that a digital equivalent of an effective RC time constant is achieved for the data reduction system which closely approximates that provided by the sound level meter, thus, in effect, satisfying the requirement for dynamic response of the data reduction system as defined in Section A36.3(d)(5) of FAR Part 36. The latter requirement is very nearly the same as specified for dynamic response of a standard sound level meter in ANSI Standard S1.4-1971.

As a matter of interest, a simplified analytical model for the dynamic response characteristics was also evaluated by assuming that the three weighting terms should correspond to the average value of $[1 - \exp(-t/\tau)]$ and $\exp(-t/\tau)$ for $t = 1.0$, 0.5 and 0 sec and $\tau = 1.0$ sec. These terms correspond to the effective build-up and decay response, respectively, of an RC network to corresponding step increases and decreases in signal input. The RC time constant (τ) of 1 sec closely corresponds to that required to satisfy the dynamic response requirements of either FAR Part 36 or ANSI S1.4-1971. The result of this analysis gave time weighting constants, normalized to sum to unity, of 0.2, 0.33 and 0.47, very close to the experimentally determined time-weighting values of 0.2, 0.35 and 0.45 for three successive time samples specified in the preceding expression.

APPENDIX B

STATISTICAL CONSIDERATIONS IN BACKGROUND NOISE CORRECTIONS

B.1 Introduction

A very simple model is desired to evaluate the statistical characteristics of the energy summation of a typical background noise, which varies randomly in time, and a specific aircraft noise level. This problem is important when considering potential errors introduced by the random nature of background noise when simple energy subtraction schemes are applied to correction "as measured" signal contaminated by background noise. The following evaluation of this problem stresses acoustic background noise since the statistical characteristics of this portion are not as well defined whereas statistics of electrical background noise can usually be well defined as characteristic of an ideal random noise (or of fixed sinusoids in the case of electrical noise dominated by power line "hum").

From analysis of a large number of surveys of the acoustic background noise in communities,[B-1, B-2] it is possible to define approximate values for several key statistical parameters of typical outdoor acoustic environments which relate to this problem.

- The instantaneous distribution in levels,
- The standard deviation of these levels and
- The approximate correlation time of the acoustic background noise.

B.2 Distribution of Instantaneous Levels

As outlined in Reference B-1, the distribution of instantaneous values of outdoor acoustic background noise levels is described by a Rayleigh distribution rather than a normal distribution. However, for purposes of this report, the two distributions are not substantially different for statistical levels in the range of L_{90} and L_{10} (levels exceeded 90 to 10 percent of the time). Thus, it is not unreasonable to assume, to a first approximation, that acoustic background noise levels are normally distributed.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1 1/A14

2.0 GENERAL NATURE OF BACKGROUND NOISE . . . 3 1/B2

2.1 Temporal and Spectral Characteristics of Background Noise 7 1/B6

2.1.1 Temporal Characteristics 9 1/B8

2.1.2 Spectral Characteristics 11 1/B10

2.2 Measurement of Background Noise Levels . . . 16 1/C1

2.2.1 Measurement of Predetection Background Noise . 16 1/C1

2.2.2 Measurement of Postdetection Background Noise 17 1/C2

2.2.3 Simple Test to Distinguish Types of Background Noise 18 1/C3

3.0 BACKGROUND NOISE CORRECTION METHODS - JET AND LARGE PROPELLER DRIVEN AIRCRAFT 19 1/C4

3.1 General Approach Currently Defined by the Regulation . 19 1/C4

3.2 Specific Approaches to Background Noise Corrections . 20 1/C5

3.2.1 Application of Band Deletion Provisions of Current Regulation 22 1/C7

3.2.2 FAA Correction Procedures 26 1/C11

3.2.3 DOT/TSC Correction Method . . . 27 1/C12

3.2.4 NASA/Dytec/Douglas Correction Methods . 27 1/C12

3.2.5 Proposed SAE Method 28 1/C13

3.2.6 Boeing Method 28 1/C13

3.2.7 BBN Method 29 1/C14

3.3 Relative Merits of Alternate Correction Methods . . 30 1/D1

3.3.1 Do-Nothing Approach 31 1/D2

3.3.2 Delete "Violating" Bands Without Replacement . 31 1/D2

3.3.3 Extrapolate in Frequency with Fixed Slope . 31 1/D2

TABLE OF CONTENTS (Continued)

3.3.4 Extrapolate, in Frequency with a Slope Based On The Available "Nonviolating" Bands . . 39 1/D10

3.3.5 Fixed Extrapolation Model in the Time Domain . 39 1/D10

3.3.6 Extrapolate in Time with a Slope Based on the Available "Nonviolating" Bands . . . 42 1/D13

3.3.7 Energy Subtraction Methods 46 1/E3

3.3.8 Combined Methods 48 1/E5

3.4 Specific Correction Methods Developed for this Report . 48 1/E5

3.5 Quantitative Comparison of Correction Methods . . 51 1/E8

3.5.1 Aircraft Signal and Background Noise Spectra Used for Evaluation 51 1/E8

3.5.2 Results 52 1/E9

3.5.3 Maximum Allowable Background Noise Level . 62 1/F6

4.0 BACKGROUND NOISE CORRECTION METHODS - LIGHT PROPELLER AIRCRAFT 63 1/F7

4.1 Analytical Basis for Correction Method . . . 63 1/F7

4.2 Field Measurement Procedure 67 1/F11

5.0 RECOMMENDATIONS FOR BACKGROUND NOISE CORRECTIONS TO NOISE CERTIFICATION MEASUREMENTS FOR AIRCRAFT . 69 1/F13

5.1 Correction Procedure for Jet and Large Propeller Aircraft 69 1/F13

5.2 Correction Procedure for Light Propeller Aircraft . . 71 1/G1

APPENDIX A - AIRCRAFT NOISE DATA ACQUISITION AND PROCESSING A-1 1/G4

APPENDIX B - STATISTICAL CONSIDERATIONS IN BACKGROUND NOISE CORRECTIONS B-1 1/G14

APPENDIX C - TIME HISTORIES OF SELECTED ONE-THIRD OCTAVE BAND LEVELS FROM ONE 727 TAKEOFF C-1 2/B1

APPENDIX D - TIME HISTORY OF MOVING MONOPOLE SOURCE IN MEDIUM WITH ATMOSPHERIC ABSORPTION LOSSES D-1 2/B5

B.3 Standard Deviation of Ambient Noise Levels

As shown in Figure B-1, the standard deviation of the instantaneous values of daytime acoustic background noise levels varies substantially and exhibits a crude trend of increasing value with decreasing value of the median (L_{50}) daytime ambient noise level. A value of 5 dB may be considered representative.

B.4 Correlation Time of Ambient or Acoustic Background Noise

The characteristic time period during which successive samples of a typical ambient noise environment will remain highly correlated is significant for two reasons.

1. The ambient noise levels should be measured, and averaged, over a time period which at least exceeds this correlation time by about 6 times to obtain minimum acceptable accuracy. This is equivalent to saying that at least six independent random samples of the ambient noise levels are required.
2. Any estimate of the ambient noise level existing during the time of the aircraft flyover can, to a first approximation, assume that the estimated level is equivalent to a new random sample from the same "population" of ambient noise levels, providing the new time period falls well outside the original measurement time by at least one correlation period. This makes it possible to apply simple statistical concepts to estimate the probable level of ambient noise that actually exists during the time of the aircraft flyover.

It is also necessary, of course, to assume that the ambient noise environment is essentially "statistically stationary" throughout the total time span including both the ambient and aircraft noise measurements. This ensures that the true mean and standard deviation of the ambient noise level will not change throughout this period.

Very limited data are available which provide direct estimates of the correlation time of ambient noise levels. A rough estimate can be made, however, for the typical case in urban and suburban areas that might be used for aircraft certification measurements where ambient noise is generally dominated by highway

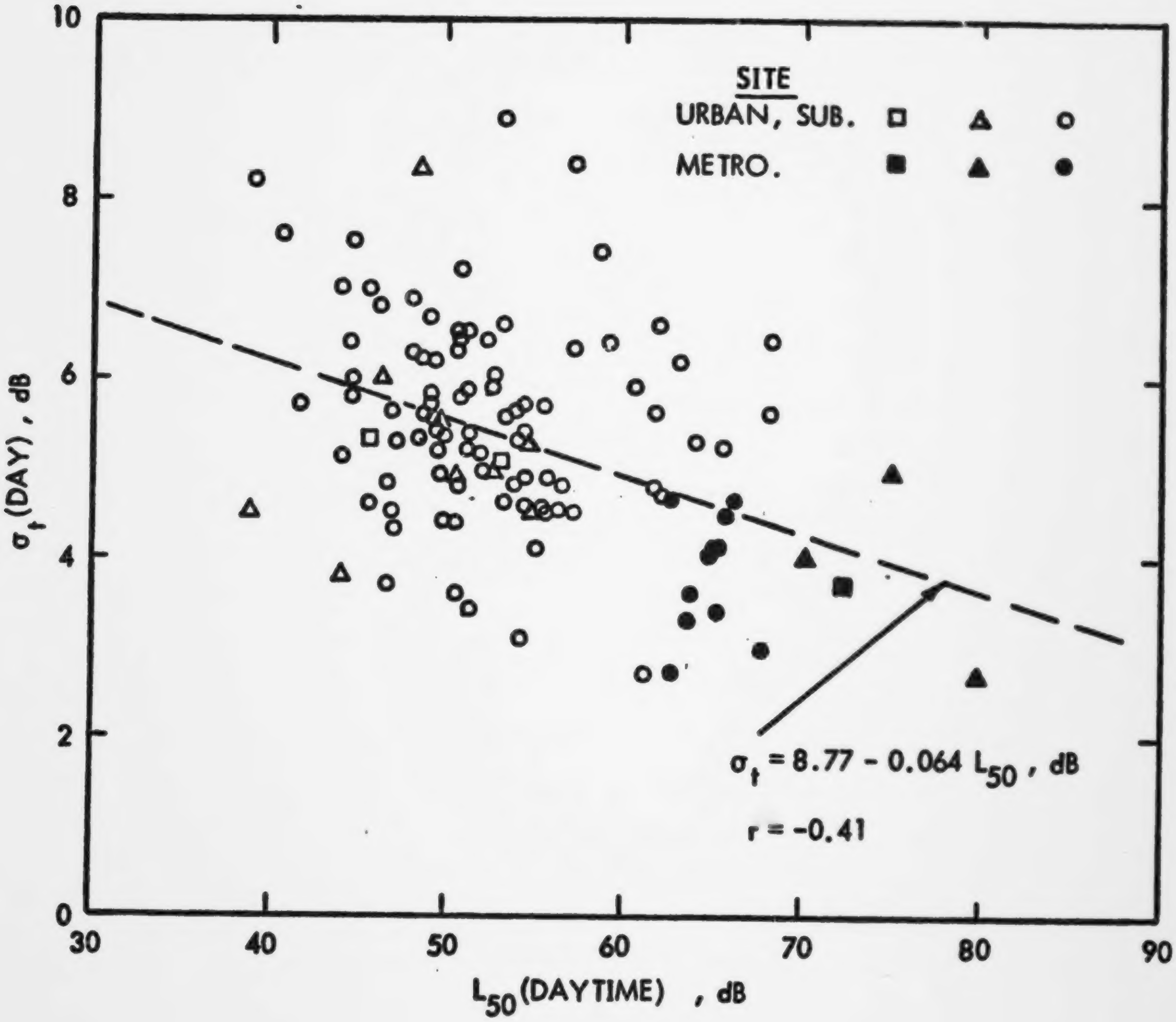


Figure B-1. Correlation Between Temporal Standard Deviation σ_t (Day) and Corresponding L_{50} During Daytime (7 AM to 10 PM) at 116 Residential Sites in Metropolitan and Urban-Suburban Areas Not Located Near Airports. Values of σ_t (Day) Are Arithmetic Averages of 15 one-hour Values from Continuous Measurements. (Open Symbols from Outdoor Measurements in Urban, Suburban Areas; Closed Symbols from Surveys in Metropolitan Areas.) (Data from Sources Defined in Reference B-1.)

traffic noise. (Good engineering practice would dictate that ambient and aircraft certification noise measurements not be made when significant noise from other aircraft is present.) Under these conditions, available information on the temporal characteristics of ambient noise levels, dominated by noise from a busy highway,[B-3] indicates that this correlation time would have a typical value of the order of 3 seconds. Thus, a 20 second sample of ambient noise (see discussion in Section 2.2, page 16) would satisfy the first requirement stated above that the measurement period should at least equal about 6 times the correlation time. Also, if the ambient noise level is measured for 10 seconds just before the test aircraft noise becomes audible and for 10 seconds just after it becomes audible, then, for normal aircraft flyovers, this will ensure that the ambient noise measurement period and the 10 dB down aircraft noise measurement period are separated by at least 3 seconds thus satisfying the second requirement concerning correlation time stated on the previous page. The net result is that it should normally be reasonable to apply the following simple statistical analysis to estimate the probability that a given ambient or acoustic background noise level will exist during the aircraft flyover and thus solve the problem posed at the beginning - namely, the statistics of the energy sum of a randomly varying noise (the ambient noise level) and a fixed (aircraft noise) signal. However, it must be emphasized that under certain circumstances, the ambient noise may have a correlation period much longer than 3 seconds. In this case, to obtain a statistically valid sample of the ambient noise, the total measurement time should be increased substantially beyond 20 seconds. This situation may occur in relatively quiet areas where significant, but infrequent, noise intrusions occur.

B.5 Energy Summation of a Fixed Signal Level and a Randomly Varying Background Noise Level

Given a fixed (aircraft) signal level, L_s, such as a single one-third octave band sound level for one particular one-half second sample, and a randomly varying background noise with a normal distribution of levels, a mean value $\overline{L_N}$, and a standard deviation σ, define the statistical characteristics of their energy sum. Assume a value of 5 dB for σ, as suggested earlier in paragraph B.3.

The probability that the random background noise level L_N will fall within the i-th range of $L_{Ni} - \Delta/2$ to $L_{Ni} + \Delta/2$ is defined from the integral of the normal probability distribution by:[B-4]

$$P(L_N = L_{Ni} \pm \Delta/2) = \frac{1}{\sqrt{2\pi}} \int_{L_{Ni} - \Delta/2}^{L_{Ni} + \Delta/2} \exp\left[-(L_N - \overline{L_N})^2 / 2\sigma^2\right] \, dL_N \qquad \text{(B-1)}$$

This is also the probability that the energy sum L_T of L_s and $L_{Ni} \pm \Delta/2$ will occur which has the value

$$L_T = 10 \log \left[10^{L_s/10} + 10^{L_{Ni}/10}\right] \quad , \text{dB} \qquad \text{(B-2)}$$

These expressions can now be applied to define the problem illustrated in Figure B-2. This illustrates how one can erroneously overestimate the true aircraft signal by applying an energy correction to the "as measured" signal plus noise based on the measured mean value of the latter. Figure B-2(a) represents the case where the actual background noise level present during the aircraft flyover was higher than the assumed mean value by at least an amount ϵ_N dB. In this case, the energy correction Δ dB, based on the mean value of the background noise level is not large enough. The result is that the "as measured" level, after correction, is high by at least the amount ϵ_s - the difference between the true aircraft signal L_s and the assumed value L_s', where the latter is based on the presumption that the background noise signal at the time of aircraft flyover, is $\overline{L_N}$ instead of its true value LN_i. The same phenomena can also cause an underestimate of the true signal after correction for a nominal background noise level.

These concepts and equations (B-1) and (B-2) were used to construct the curves in Figure B-3 which define the probability of over or underestimating the true signal level from just one measurement by the amounts specified after applying an energy correction for a background noise level based on its mean level. The background noise is assumed to be wide-band random noise with normally distributed instantaneous levels and a standard deviation of 5 dB.

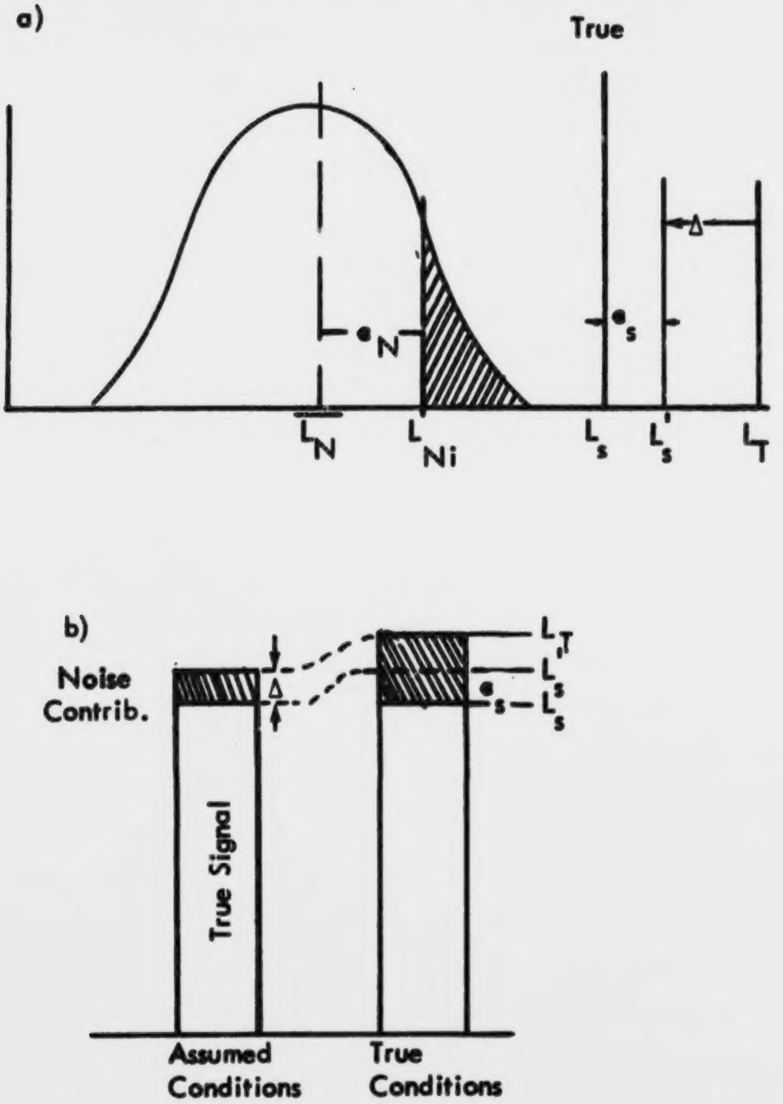


Figure B-2. Conceptual Illustration of Applying an Energy Subtraction (Δ) to Correct an "As Measured" Signal + Noise (L_T) for the Background Noise (L_N). This can result in an overestimate (L'_s) of the true signal (L_s) by a residual error (e_s) due to the random variation (e_N) of the background noise level (L_{Ni}) about its mean value ($\overline{L_N}$).

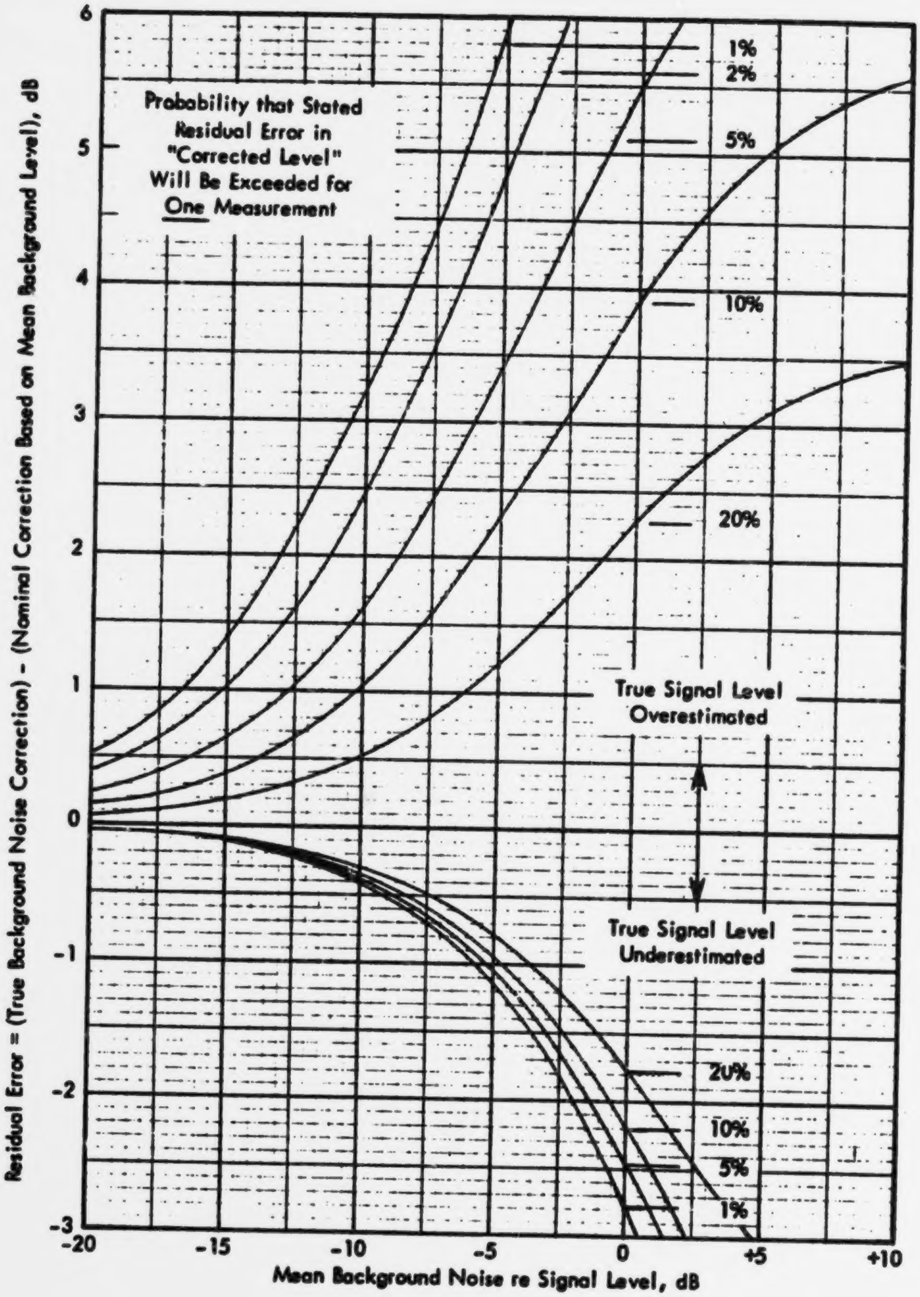


Figure B-3. Residual Error in Applying Energy Subtraction Correction Due to Random Variation of Background Noise Between Time of Its Measurement and Time of Aircraft Flyover. (Standard Deviation of Background Noise 5 dB.)

For example, if the mean background noise level is 10 dB below the true signal level, application of the nominal energy correction to the measured signal plus noise will, 20 percent of the time, result in a residual overestimate of the true signal by at least 0.5 dB or an underestimate of the true signal by at least 0.3 dB. The corresponding residual errors that would be exceeded 5 percent of the time are approximately 1.6 dB (overestimate) or 0.4 dB (underestimate) respectively.

This seems to represent a potentially large error when energy subtraction is applied to correct a contaminated signal for random background noise. However, two factors will prevent such large errors from occurring in the final result. First, the data on Figure B-3 is the probable error for just one measurement. Since a miminum of 6 flybys are presently required by the Regulation for each certification measurement, the overall probability that the residual error defined in Figure B-3 will occur in the final mean certification level is drastically reduced. For example if the probability of exceeding a 0.5 dB error is 20 percent for just one measurement, the joint probability that each measurement of the same one-third octave band level would be overestimated by at least 0.5 dB for all six overflights would be the sixth power of the probability for just one occurrence, or:

$$P(\epsilon \geq 0.5) = P(\epsilon_i \geq 0.5)^6 = 0.2^6 = 6.4 \times 10^{-5} \text{ or } <0.01\%$$

Clearly this is a negligible risk.

A further analysis has shown that the following expression defines the required "as measured" signal-to-noise ratio (S/N), in dB, as a function of the allowable residual error (ϵ) in dB and the deviation ($L_{Ni} - \overline{L_N}$) of the actual background noise level (L_{NI}) at the time of aircraft flyover, from the mean value ($\overline{L_N}$) measured for the background noise alone. The "as measured" signal-to-noise ratio is the difference between the aircraft signal plus background noise at the time of the aircraft flyover minus $\overline{L_N}$. This required value for S/N is given by:

$$S/N = L_T - \overline{L_N} = 10 \log \left[\frac{\left(10^{(L_{Ni} - \overline{L_N})/10}\right)\left(10^{\epsilon/10}\right) - 1}{10^{\epsilon/10} - 1} \right] \text{, dB} \qquad \text{(B-3)}$$

This expression has been evaluated for an assumed normal distribution of background noise levels and a range of standard deviations from 2 to 10 dB. The result, given in Figure B-4, shows the relationship between the signal-to-noise ratio (S/N) and σ for specified values of the final residual error (ϵ) based on the average of six separate tests and the probability (P) of exceeding this error. Considering only negative values of ϵ as representing the more critical case of an underestimate of the true signal by this amount, a very rough rule of thumb is provided by the following simple expression for the required S/N for the case $P \leq 0.1$ percent that $\epsilon \leq -0.5$ dB or for the case $P \leq 1$ percent that $\epsilon \leq -0.1$ dB. That is:

$$S/N \geq 4 + 0.6\,\sigma \quad , \text{dB} \tag{B-4}$$

Thus, for a typical standard deviation for acoustic ambient background noise of 5 dB, an "as measured" signal-to-noise ratio of 7 dB is required to achieve the specified accuracy after averaging results from six separate tests. This ideal model has necessarily assumed that the background remains statistically stationary throughout the tests. Applying about a 50 percent safety factor to this ideal situation, a practical rule of thumb could be stated as requiring that $S/N \geq 5 + \sigma$ dB to be 99 percent sure that the true aircraft signal, after applying an energy correction for the background noise, would not be underestimated by more than 0.1 dB, neglecting all other errors.

The other reason why this residual error is expected to be small for aircraft measured under Appendix A procedures of the Regulation is based on the fact that the error will approach a minimum during the course of an aircraft flyby as the one-half second samples of the aircraft signal approach PNLTM. In other words, there will be many more than just six measurements involved for each frequency band so that, in general, this random residual error will be expected to average out to essentially zero, even for a very low value of the difference between the mean background noise level and the signal level.

In summary, the potential residual error introduced by the randomness of background noise into a set of six aircraft noise measurements, each of which have been corrected by energy subtraction for the nominal mean background noise level, can be reduced to very small values for practical signal-to-noise ratios.

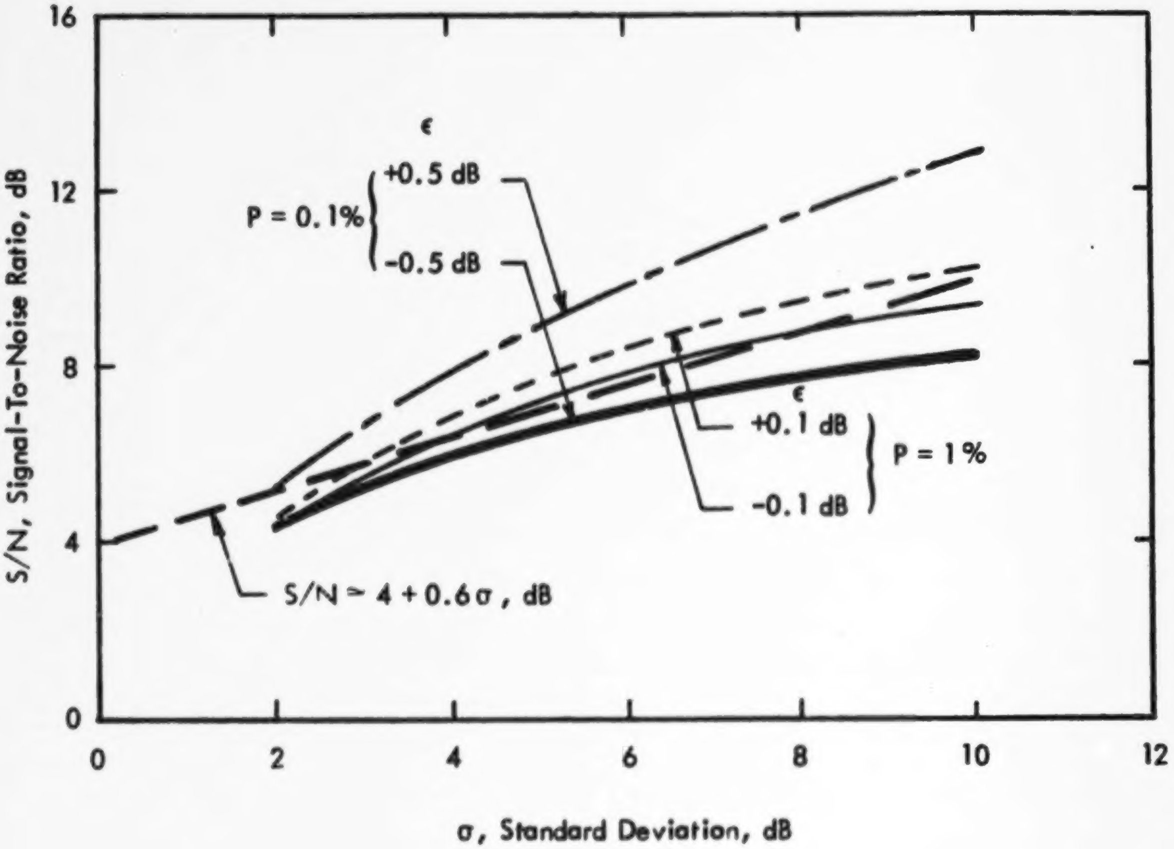


Figure B-4. Required "As Measured" Signal-to-Noise (S/N), in dB, as a Function of Standard Deviation (σ) for Background Noise with Residual Error (ϵ) after Six Separate Tests and Probability (P) of Exceeding This Error as Parameters. (Negative Value of Residual Error ϵ Implies Underestimate of True Aircraft Noise Level.)

B.6 Statistical Error in Measurement of the Mean Background Noise Level

One final point should be made about application of an energy subtraction correction for background noise. This concerns the inherent error in measuring its true mean level. As suggested earlier, a 20 second measurement period for the background noise measurement (i.e., 10 seconds before and 10 seconds after the aircraft flight) will probably satisfy a minimum requirement for the duration of the background noise sample. For relatively quiet areas, free of significant intrusions of high ambient noise levels, where one would like to conduct aircraft noise certification measurements, a measurement period of 20 seconds should be sufficient to estimate the mean background noise level within 95 percent confidence limits of about ± 3 dB providing the elapsed time between the background noise measurement and the aircraft noise measurement does not exceed more than a few minutes. However, evaluation of the relative accuracy of outdoor community noise level measurements as a function of observation time[B-5] seems to indicate that one should measure background noise for a longer period than 20 seconds in certain types of locations where the acoustic background noise is subject to large fluctuations. In this case, the following field measurement procedure is recommended to achieve the desired statistical accuracy for the acoustic background noise level.

B.6.1 Field Measurement of Acoustic Background Noise Level

Prior to recording the ambient or acoustic background noise level, the steps defined below should be carried out using a standard sound level meter set to the A-scale and SLOW response.

1. Read, every 15 seconds, a "snapshot" value of the instantaneous acoustic background noise level for a period of 5 minutes, providing a total of 20 readings.

2. Make an initial estimate of the true standard deviation, σ, of the background noise level. Base this estimate on the 20 "snapshot" samples using the conventional expression for a large random sample

$$\sigma \simeq \left[\sum^{n} L_i^2/n - \left(\sum^{n} L_i/n \right)^2 \right]^{1/2} \quad \text{, dB} \qquad \text{(B-5)}$$

where

L_i = the i-th "snapshot" reading of L_n

n = number of samples (nominally 20)

3. If this initial estimate of σ is 4 dB or less, proceed to record the background noise for a sample period of 20 seconds (i.e., at least 10 seconds before and 10 seconds after each flight).

4. If the initial estimate of σ is greater than 4 dB, use the following expression to compute a new duration, T, for the length of the background noise recording in order to retain approximately the same degree of accuracy. The expression is

$$T \simeq 20\,[\sigma/4]^2 \quad \text{, seconds} \qquad \text{(B-6)}$$

This procedure for increasing the sample duration for the measurement of the background noise is based on the following rationale.

Assume that the fluctuating background noise levels can be represented statistically as a normally distributed population of random variables. Further assume that the nominal 20 second measurement period is equivalent to a sample size of 20 independent 1 second samples when the background noise is measured on a system with "SLOW" dynamic response (i.e., the correlation time of the analyzer and of the level fluctuations are both of the order of 1 second.[B-3, B-6] The theory for accuracy of random samples drawn from a normally distributed population[B-4] defines the required sample size n, for a 90 percent confidence interval, as[B-4]

$$n \simeq [1.7\,\sigma\ /\text{C.I.}]^2 \qquad \text{(B-7)}$$

where

1.7 $\simeq$ value of t parameter for 90 percent degree of confidence and sample size $n > 20$

σ = standard deviation of population, dB

C.I. = confidence interval, dB

Based on n = 20, and a confidence interval of ± 1.5 dB, a value of σ of approximately 4 dB satisfies Eq. (B-6). Thus, if the same degree of confidence and the same confidence interval is to be maintained for higher values of the population standard deviation, then a larger sample (i.e., a larger sample period) is desired and the proportional relationship in Eq. (B-6) is obtained.

REFERENCES

B-1. Sutherland, L. C., "Indoor Noise Environments Due to Outdoor Noise Sources," Noise Control Engineering 11(3), 124-137, November-December 1978.

B-2. Data in Wyle Research files.

B-3. Sutherland, L. C. and Ollerhead, J. B., "Temporal Fluctation in Community Noise Levels - A Brief Review," Paper V10 presented at 96th Meeting, Acoustical Society of America, Honolulu, Hawaii, 27 November - 1 December 1978.

B-4. Freund, John E., Mathematical Statistics, 2nd Edition, Prentice Hall, Inc., 1971.

B-5. Eldred, K. and Wyle Research Staff, "Community Noise," U. S. Environmental Protection Agency Report No. NTID 300.3, Wyle Research, El Segundo, California, 1971.

B.6 American National Standards Institute, Inc., "American National Standard Specification for Sound Level Meters," ANSI S1.-4, 1971.

APPENDIX C

TIME HISTORIES OF SELECTED ONE-THIRD OCTAVE BAND LEVELS FROM ONE 727 TAKEOFF

Measurement Position	Takeoff Location as defined in Table A-1 of Appendix A.	
Microphone Positions	0.0127 m, 1.2 m and 10 m over concrete surface (see Legend in Figure).	
Aircraft Altitude at Overhead	244	m
Aircraft Speed	80	m/s
Aircraft Mach No.	0.233	
Temperature	20°	Celsius
Relative Humidity	75	Percent

Time on all plots on the following pages is relative to the time when the aircraft is overhead. The "10 dB down" period, based on the PNLT time history for the 1.2 m microphone, extends from -3 sec to +6.5 sec.

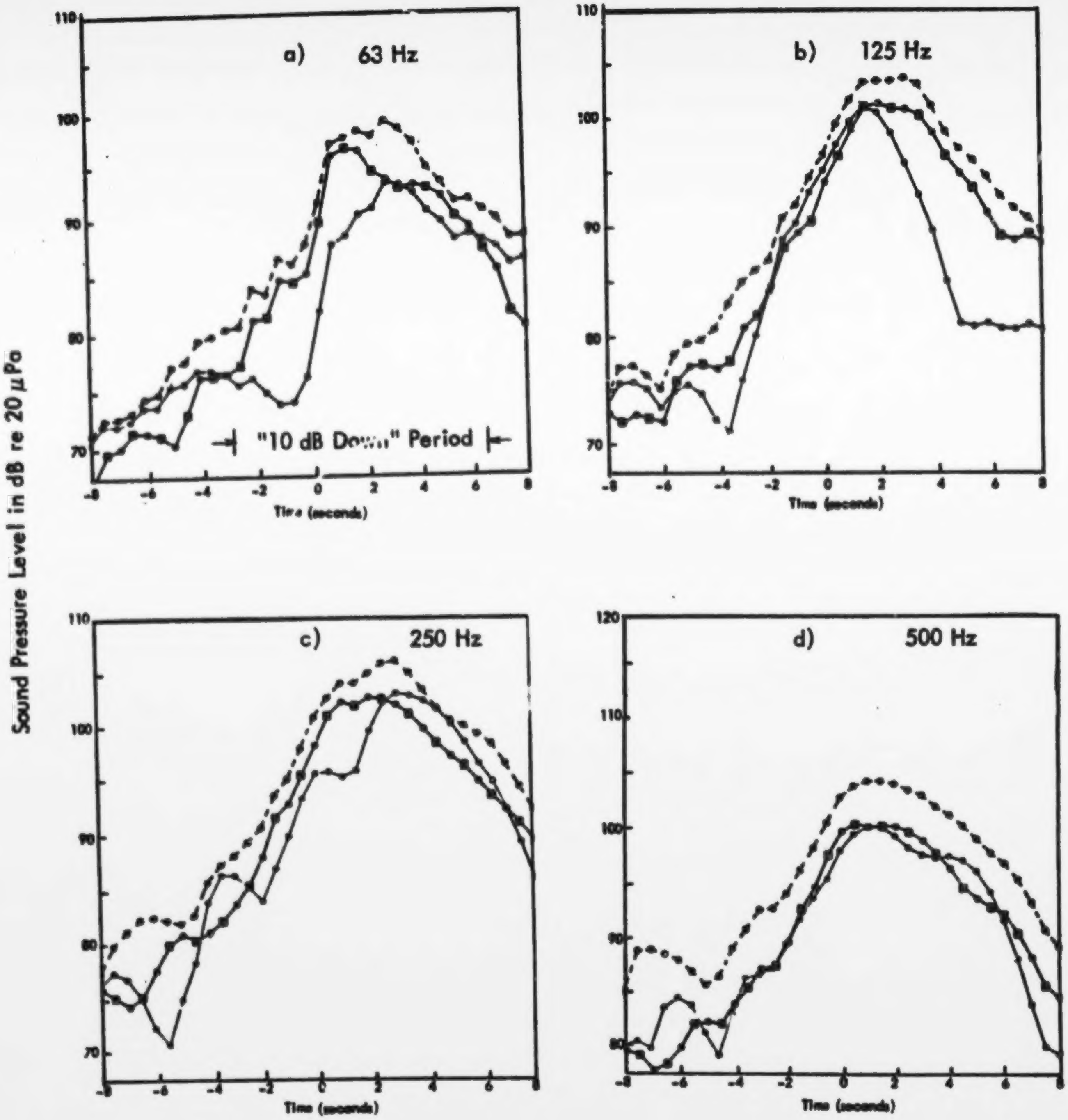


Figure C-1. Time Histories of Selected One-Third Octave Band Levels for 727 at Takeoff - Measured Simultaneously with Three Microphone Positions; —●— — for 0.0127 m, —○— for 1.2 m, and —■——●— for 10 m.

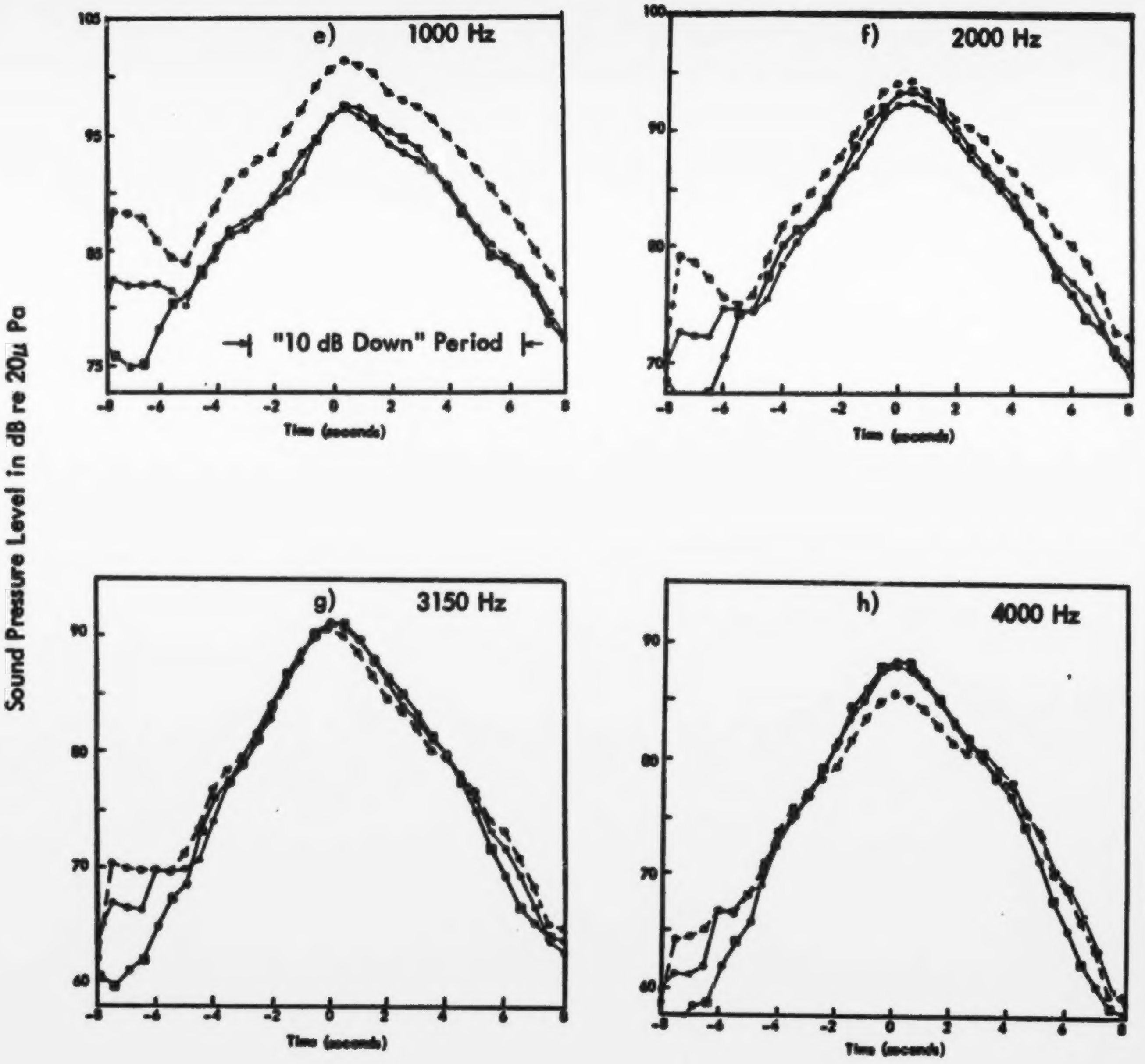


Figure C-1 (Continued)

- - ● - - 0.0127 m

—○— 1.2 m

—■—●— 10 m

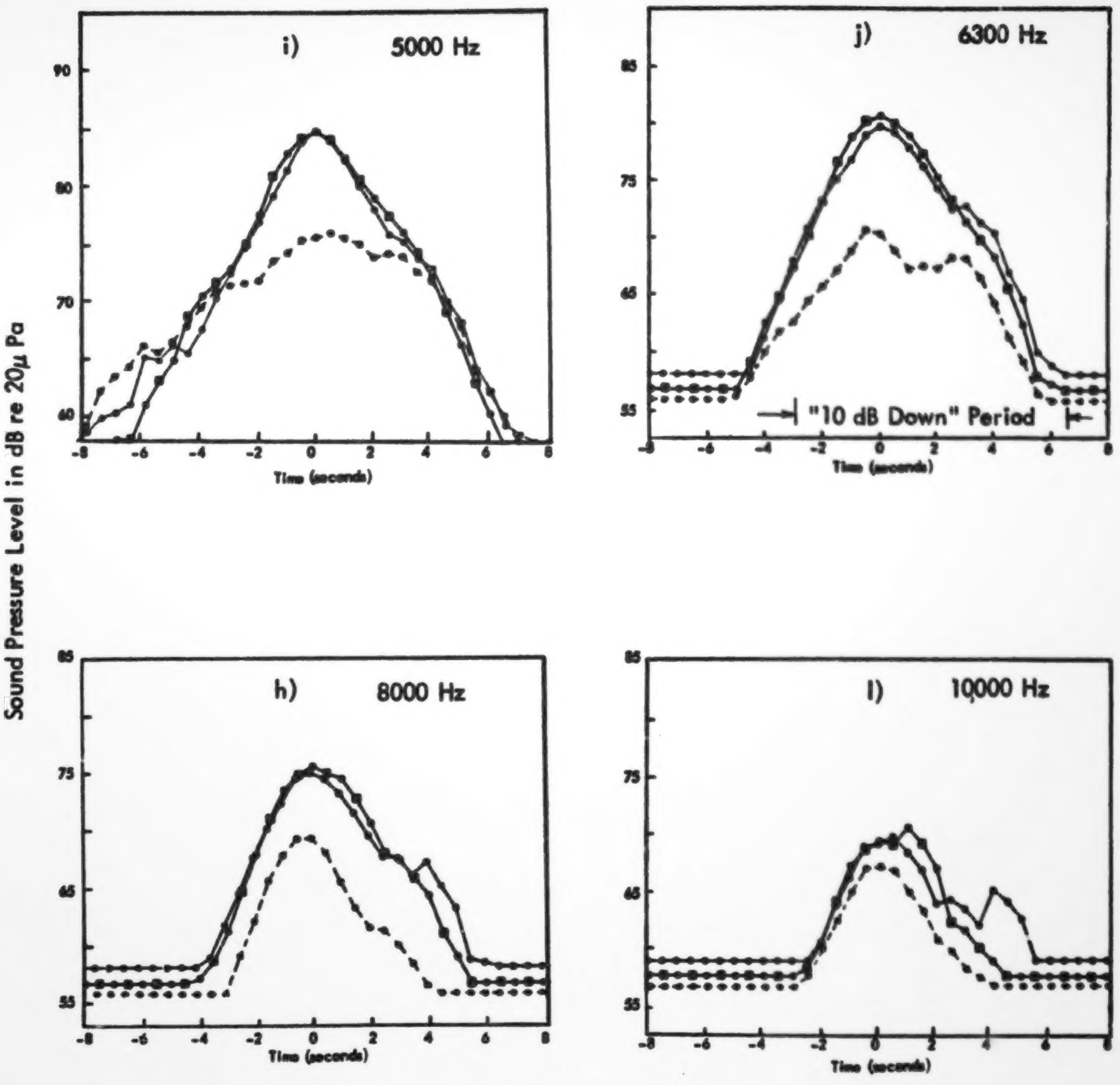


Figure C-1 (Concluded)

APPENDIX D

TIME HISTORY OF MOVING MONOPOLE SOURCE IN MEDIUM WITH ATMOSPHERIC ABSORPTION LOSSES

D.1. INTRODUCTION - THE CASE FOR THE IDEAL MEDIUM

There were two types of solutions for the observed sound level near a monopole source moving in a lossless medium with a constant velocity V along a straight line

D.1.1 Kinematic Solution

The first, or Kinematic, solution defines the time history of the sound intensity I(t) observed at a time t and distance Y from the source path as follows. (The coordinate origin, x, y = 0, falls on the source path opposite the receiver.)

$$I(t) = \frac{I_o (r_o/Y)^2 (1 - M^2)^2}{\left[-M\tau + \sqrt{\tau^2 + (1 - M^2)}\right]^2} \text{, watts/m}^2 \qquad \text{(D-1)}$$

where

I_o = sound intensity at reference distance r_o, watts/m^2

M = V/c, source Mach No

c = speed of sound, m/sec

τ = Vt/Y, a dimensionless time

This solution considers only the retarded time associated with the finite speed of sound and source motion but neglects any effect of motion on the acoustic output of the source. A special case of the Kinematic solution can be called the "static" solution which ignores the retarded time effect altogether and is obtained from Eq. (D-1) by setting M = 0.

D.1.2 Acoustic Solution

The second, or acoustic, solution is the exact one which accounts for the effect of motion on the acoustic output of the source.[D-1] (Superscripts denote references at the end of this appendix.) The time history of sound level L(t) for this case can be shown to be the following. This neglects a minor second order term which is only significant in the very near field for $Y \ll \lambda/2\pi$, where λ = wavelength.[D-1]

$$L(t) = L_o + 10 \log (r_o/Y)^2 + 20 \log \left\{ \left[R(\tau)/Y \right] / \left[\tau^2 + (1 - M^2) \right] \right\} \qquad \text{(D-2)}$$

where $R(\tau) = Y \left[-M\tau + \sqrt{\tau^2 + (1 - M^2)} \right] / (1 - M^2)$, the time varying propagation path length, in meters.

Consider, now, how Equations (D-1) and (D-2) change when atmospheric absorption is included.

D.2. TIME HISTORY INCLUDING AIR ABSORPTION LOSSES

D.2.1 Kinematic Model

For propagation through a real atmosphere, absorption losses introduce an exponential loss term in Equations (D-1) and (D-2). For the Kinematic model, the general expression for the time history of the observed intensity is:

$$I(t) = I_o \left[r_o^2 / R^2(t) \right] \exp \left[-2\alpha R(t) \right] \quad \text{, watts/m}^2 \qquad \text{(D-3)}$$

where

$R(t)$ = the time-varying propagation path length and

α = absorption coefficient for pressure, N_p/m

For convenience, divide Y out of the quantity R(t) and then replace $2\alpha Y$ with the equivalent value in terms of the excess attenuation A_e, in decibels, over the minimum propagation distance Y to give

$$A_e = -10 \log_{10} \left[\exp(-2\alpha Y) \right] = 20 \alpha Y \log_{10} e \quad \text{, dB}$$

or

$$2\alpha Y = A_e / 10 \log_{10} e = 0.23026 A_e \simeq 0.23 A_e \qquad \text{(D-4)}$$

The resulting time history of sound level L(t) observed near a monopole source moving with constant velocity in a real (lossy) medium, ignoring convective amplification effects given by the acoustics solution, can be expressed as:

$$L(t) = L_{max} + C(t) \quad , \text{dB} \qquad \text{(D-5)}$$

where

$$L_{max} = L_o + 10 \log (r_o/Y)^2 - A_e, \text{ the maximum level during passby, dB}$$

and

$$C(t) = 10 \log \left\{ \frac{(1 - M^2)^2 \exp\left[- 0.23\, A_e \left[- M\tau + \sqrt{\tau^2 + (1 - M^2)} \right] / (1 - M^2) \right]}{\left[- M\tau + \sqrt{\tau^2 + (1 - M^2)} \right]^2} \right\} + A_e \text{ ,dB}$$

D.2.2 Acoustic Model

To include air absorption losses in the acoustic model to a first approximation, it is only necessary to add the quantity $-A_e R(\tau)/Y$ to Eq. (D-2) where $R(\tau)$ is the same time-varying propagation path length defined for Eq. (D-2).

D.3. 10 dB DOWN TIME

D.3.1 Ideal Medium

For the ideal medium, when the speed of sound is assumed infinite (M = 0), the "10 dB down time," t_{10}, is readily found from Eq. (D-1), as follows

$$I(t = t_{10}) = 0.1\, I_{max} = I_{max}/(1 + \tau_{10}{}^2), \quad \text{watts/m}^2 \qquad \text{(D-6)}$$

where $I_{max} = I_o(r_o/Y)^2$, the maximum passby intensity.

Solving Eq. (D-6) for τ_{10},

$$(\tau_{10})^2 = 9 \text{ or } \tau_{10} = \pm 3$$

so that

$$\tau_{10} = 6 \qquad \text{(D-7)}$$

It turns out that for the Kinematic model, this 10 dB down time is independent of Mach. No. so only the case for M = 0 need be considered. This is not true, however, for the true acoustic solution. However, this more complex problem is not treated further here.

D.3.2 Lossy Medium

For the real medium, numerical evaluation of Eq. (D-5) was carried out to define the nondimensional "10 dB down time" τ_{10} for this case. The following values of τ_{10} were found as a function of the total attenuation A_e over the minimum distance Y.

Table D-1

10 dB Down Duration, τ_{10}, as a Function of the
Total Air Absorption Loss A_e Over the Minimum Propagation Path
Near a Moving Monopole Source (Kinematic Solution)

A_e	dB	0	0.01	0.03	0.1	0.3	1	3	10	30	100
τ_{10}	-	6	5.9835	5.9509	5.8415	5.5628	4.8503	3.7749	2.4843	1.5502	0.8790
$10 \log (\tau_{10}/6)$	dB	0	-0.0120	-0.0357	-0.1163	-0.3285	-0.9238	-2.0125	-3.8295	-5.8777	-8.3415

Plotting 10 log ($\tau_{10}/6$) vs A_e on a log-log scale, it was found that the following expression approximated the above true values of τ_{10} within an average absolute error of ± 0.2 percent for A_e from 0.01 to 100 dB.

$$10 \log (\;_{10}/6) \qquad - A_e / \quad 0.820 + 0.281\, A_e^{0.8} \qquad , \text{dB} \qquad\qquad \text{(D-8)}$$

D.4. RATE OF CHANGE OF LEVEL - KINEMATIC SOLUTION

These analytical models could now be applied to the extrapolation of a noise time history, when necessary, to recover a signal from a high ambient noise floor. Consider, first, the case for an ideal medium.

D.4.1 Ideal Medium

If the Level $L(t) = 10 \log_{10}\left[I(t)/I_o\right]$ dB,

then letting ' signify differentiation with time, the rate of change of level with time is:

$$L'(t) = 10\left[\frac{I_o}{I(t)}\right]\left[\log_{10} e\right]\left[I'(t)/I_o\right] = 4.343\, I'(t)/I(t) \quad \text{, db/sec} \qquad \text{(D-8)}$$

For the case where finite speed of sound effects are neglected, then for $\tau = tV/Y$,

$$I(t) = I_{max}/(1 + \tau^2)$$

and

$$I'(t) = I_{max}(-2\tau \frac{V}{Y})/(1 + \tau^2)^2$$

Therefore, $$I'(t)/I(t) = -2\tau(V/Y)/(1 + \tau^2) \quad \text{,sec}^{-1}$$

and the corresponding rate of change of level with time is

$$L'(t) = -8.686\,\tau(V/Y)/(1 + \tau^2) \quad \text{, dB/sec}$$

For example, for t = the 10 dB down time, it was shown by Eq. (D-6) that $\tau_{10} = \pm 3$, and the corresponding rate of change of level will be

$$L'(\tau_{10}) = \mp 2.606\, V/Y \quad \text{, dB/sec} \qquad \text{(D-9)}$$

D.4.2 Lossy Medium

For this case, again neglecting finite speed of sound effects (i.e., M = 0), I(t) will be given by

$$I(t) = I_{max} \exp\left[-A_e\sqrt{1 + \tau^2}\right]\Big/\left[1 + \tau^2\right] \quad \text{, watts/m}^2 \qquad \text{(D-10)}$$

and applying Eq. (D-8), the rate of change of level will be:

$$L'(t) = -8.686\,(V/Y)\left[\frac{\tau}{1 + \tau^2} + \frac{A_e}{2}\frac{\tau}{\sqrt{1 + \tau^2}}\right] \quad \text{, dB/sec} \qquad \text{(D-11)}$$

This expression is plotted in Figure D-1 for positive values of the dimensionless time τ from +1 to +4 and for values of the total air absorption loss, A_e, over the minimum propagation path (or slant range) of 0 to 100 dB. The important point brought out by this graph is that for reasonable values of A_e (typically in the range of 10 to 100 dB), the rate of change of level with time is nearly constant for a wide range of the dimensionless time τ. Thus, as indicated by the sketch in Figure D-1, it would be possible to approximate the "tails" of the time history of sound level observed near a simple moving noise source by a simple linear extrapolation where a constant slope of the extrapolation line could be estimated on the basis of Figure D-1 or the analytical models used to generate it.

Note that for the Kinematic solution to the moving source problem, the time history of noise level is simply displaced along the time axis as the function of the source Mach No. This does not influence the rate of change of level with time, L'(t), plotted in Figure D-1 - only the time axis is shifted.

REFERENCES

D-1 Morse, P. M. and Ingard, K. U., Theoretical Acoustics, McGraw-Hill Book Co., New York, 1968.

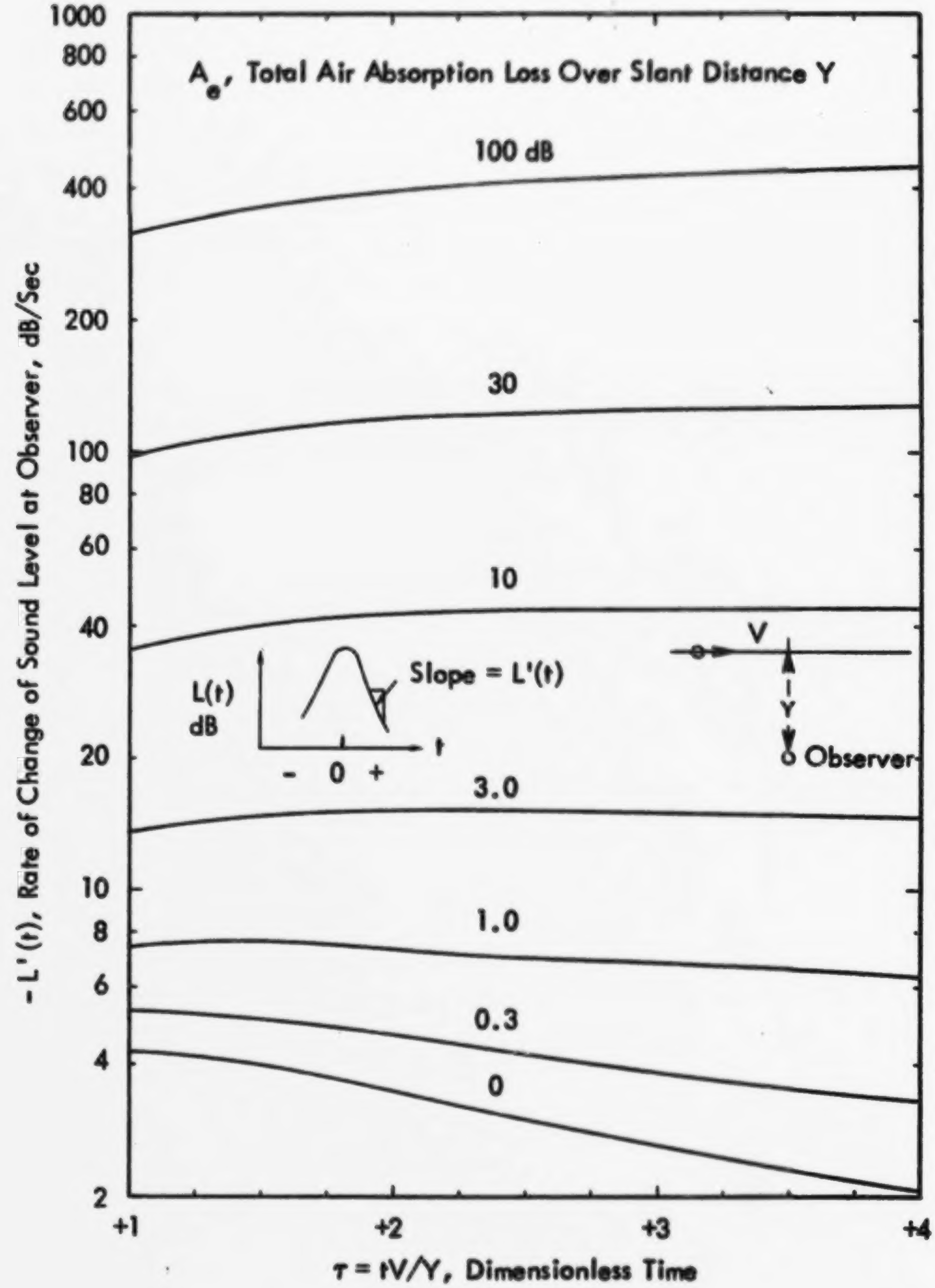


Figure D-1. Rate of Change of Level Observed Near Simple Moving Monopole Source in a Uniform, Still, Lossy Atmosphere